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REVISION 1 TO SEPARATION PROCEDURES FOR APOLLO 12 (MISSION H-1) NOMINAL, ALTERNATE, AND ABORT MISSIONS

Flight Analysis Branch
MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

REVISION 1 TO SEPARATION PROCEDURES FOR APOLLO 12 (MISSION H-1) NOMINAL, ALTERNATE, AND ABORT MISSIONS

By Flight Studies Section
Flight Analysis Branch

November 7, 1969

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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FOREWORD

Revision I to the separation procedures document has been updated to present only those separation procedures that may be used during the Apollo 12 mission. Nominal separation timelines and attitudes were updated to reflect the current mission profile as contained in references 4 and 5.

Procedures described in this document are based on the following Apollo 12 documentation: Flight Mission Rules, Apollo Mission Techniques, Apollo Abort Summary Procedures by FCSD, Operational Trajectories (SC and LV), Operational Spacecraft Attitude Sequence.

This document has been reviewed by the Flight Control Division, the Flight Crew Support Division, the Apollo Data Priority Control group, and by MPAD mission engineers.

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REVISION 1 TO SEPARATION PROCEDURES FOR APOLLO 12

(MISSION H-1) NOMINAL, ALTERNATE, AND ABORT MISSIONS

By Flight Studies Section

1.0 SUMMARY AND INTRODUCTION

Separation techniques and procedures for the Apollo 12 nominal, abort, and alternate missions are presented in this document. The procedures are listed by the following mission phases.

a. Launch

b. Earth orbit

c. Translunar injection (TLI)

d. Translunar coast (TLC)

e. Lunar orbit

f. Transearth coast (TEC)

g. Entry

Under each phase, the separation procedures are identified by vehicle interface and kind of mission (i.e., nominal, abort, or alternate). Illustrations and relative motion plots for each procedure are included. The nominal separation procedures are presented under the TLC, lunar orbit, and entry phases.

Local horizontal command/service module (CSM) attitudes are shown in the the order of rotation. A CSM local vertical/local horizontal (LVLH) attitude of pitch 0°, yaw 0°, and roll 0° alines the CSM +X-axis with the positive local horizontal in a heads-up attitude. The CSM LVLH attitudes presented in this document are referenced from a 0, 0, 0 attitude.

Times and gimbal angles presented in this document are based on a launch at $16^h22^m00^s$ G.m.t., November 14, 1969, on a 72° flight aximuth. Gimbal angles are based on the best preflight trajectory data available; however, because they are time and trajectory dependent, they may be updated in real time with MCC-H ground-computed values.

All mission variables (i.e., conditional items such as gimbal angles, g.e.t.) presented in this document are underlined. Underlined items are subject to real-time updates by MCC-H.

2.0 SYMBOLS

APS	ascent propulsion system
CDH	constant differential height
CM	command module
CMP	command module pilot
COI	contingency orbit insertion
CR	cross range
CSM	command/service module
DOI	descent orbit insertion
DPS	descent propulsion system
DRPA	docking ring/probe adapter
EI	entry interface (400 000 ft)
IMU	inertial measurement unit
LET	launch escape tower
LH	local horizontal
LH_2	liquid hydrogen
LM	lunar module

LOI	lunar orbit insertion
LOS	line of sight
LOX	liquid oxygen
LV	local vertical
MCC	midcourse correction
MCC-H	Mission Control Center - Houston
REFSMMAT	reference to stable member matrix
RCS	reaction control system
R_{ip}	predicted full-lift landing range from the launch pad
SC	spacecraft (CSM)
SEP	separation
SLA	spacecraft/LM adapter
SM	service module
SPS	service propulsion system
T, D, and E	transposition, docking, and extraction
TEC	transearth coast
TEI	transearth injection
TLC	translunar coast
TLI	translunar injection
TPF	terminal phase finalization
TPI	terminal phase initiation
t_{ff}	time of free-fall from EI

V_i	inertial velocity
Δt	delta time
ΔV	delta velocity

3.0 LAUNCH PHASE

3.1 Aborts from a stable (nontumbling) launch vehicle
(For detailed descriptions of mode I, II, and III aborts and contingency orbit insertions, see reference 1.)

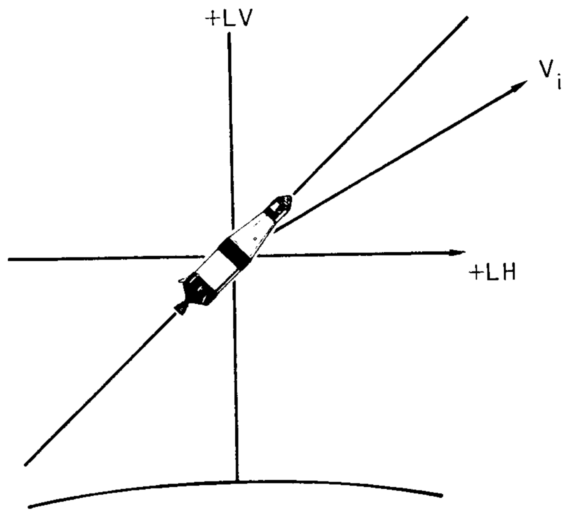
3.1.1 Mode I aborts (from LET arming through LET jettison)

a. Mode I aborts are LET jettisons of the CM from the LV.
b. The SM and the SLA panels remain attached to the LV.
c. The DRPA is jettisoned with and remains attached to the LET.
d. For detailed mode I sequencing and profile drawings, see reference 1.

3.1.2 Mode II aborts (from LET jettison through R_{ip} = 3200 n. mi.) (figs. 1 and 2)

a. The abort is initiated; the booster is cut off; and the CSM +X RCS four-jet ullage is ON.
b. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.
c. Terminate CSM +X translation 24 seconds after abort initiation.
d. Immediately after termination of the CSM RCS translation,
   1. If t_{ff} > 2 minutes, yaw CSM +X-axis 45° north out of plane and jettison the SM.
   2. If t_{ff} < 2 minutes, jettison the SM inplane.
e. Orient the CM to entry attitude.
f. Jettison the DRPA.

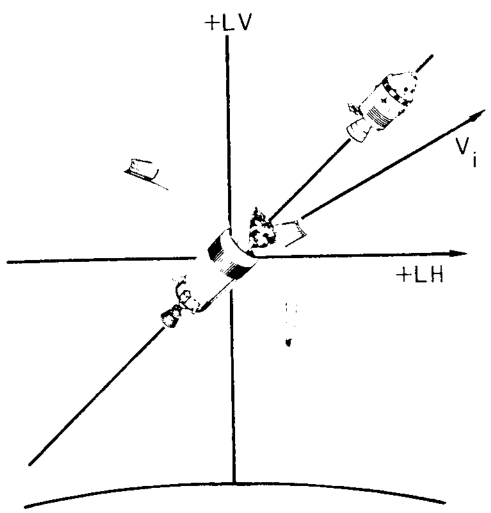
CSM SEPARATION ATTITUDE



LVLH CSM ATTITUDE

Y = 000
P = VARIABLE DEPENDING ON
TIME OF ABORT, APPROXIMATELY
005 TO 026
R = 180

CSM SEPARATES FROM S-IVB



- ABORT INITIATED, S-IVB SHUTDOWN
- CSM PERFORMS +X RCS FOR 24 SEC
- CSM PHYSICAL SEPARATION OCCURS AT 3 SEC
- RCS CUTOFF AT 24 SEC
- IMMEDIATELY AFTER CUTOFF, JETTISON SM OUT-OF-PLANE IF T_{ff} >2 MIN OR INPLANE IF T_{ff} <2 MIN
- ORIENT CM TO ENTRY ATTITUDE
- JETTISON DRPA

Figure 1.- Case: CSM separation from the SLA/LM/S-IVB; condition: mode II abort, launch phase.

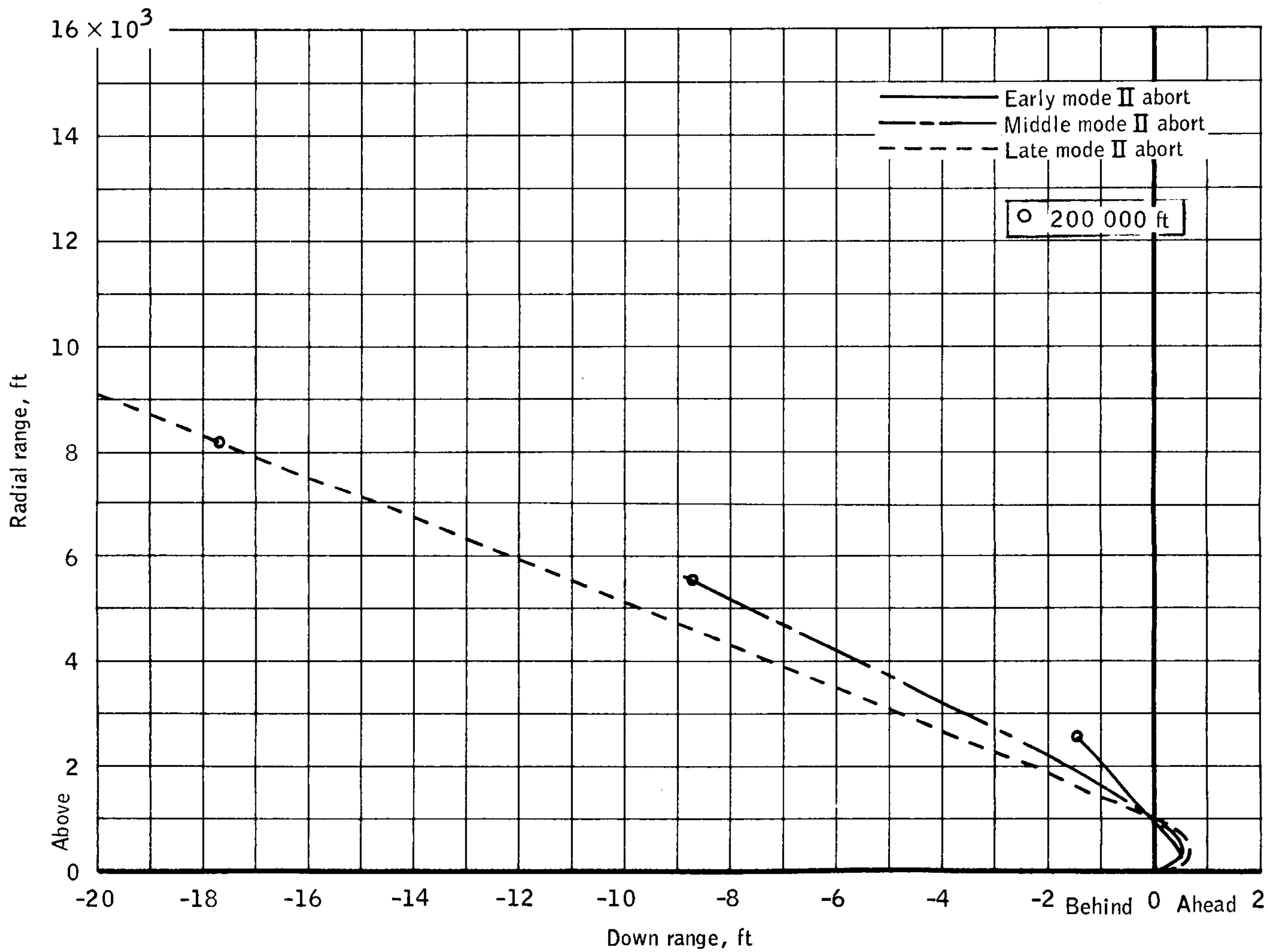


Figure 2.- Motion of the CSM relative to the S-IVB for mode II aborts.

3.1.3 Mode III aborts (from R_{ip} > 3200 n. mi. until the required SPS burn violates the 100-sec t_{ff} constraint) (figs. 3, 4, and 5)

a. Abort is initiated; booster is cut off; and CSM +X RCS four-jet ullage is ON.
b. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.
c. Terminate CSM +X translation 24 seconds after abort initiation.
d. Orient to the mode III abort burn attitude: CSM heads up, CSM +X-axis 31.7° below the LOS to the rearward horizon; begin attitude hold and perform the required SPS abort burn.
e. Immediately after SPS cutoff,
   1. If t_{ff} > 2 minutes, yaw the CSM +X-axis 45° south out of plane and jettison the SM and DRPA.
   2. If t_{ff} < 2 minutes, jettison the SM and DRPA inplane.
f. Orient the CM to entry attitude.
g. For a detailed description of the mode III abort region, see reference 1.

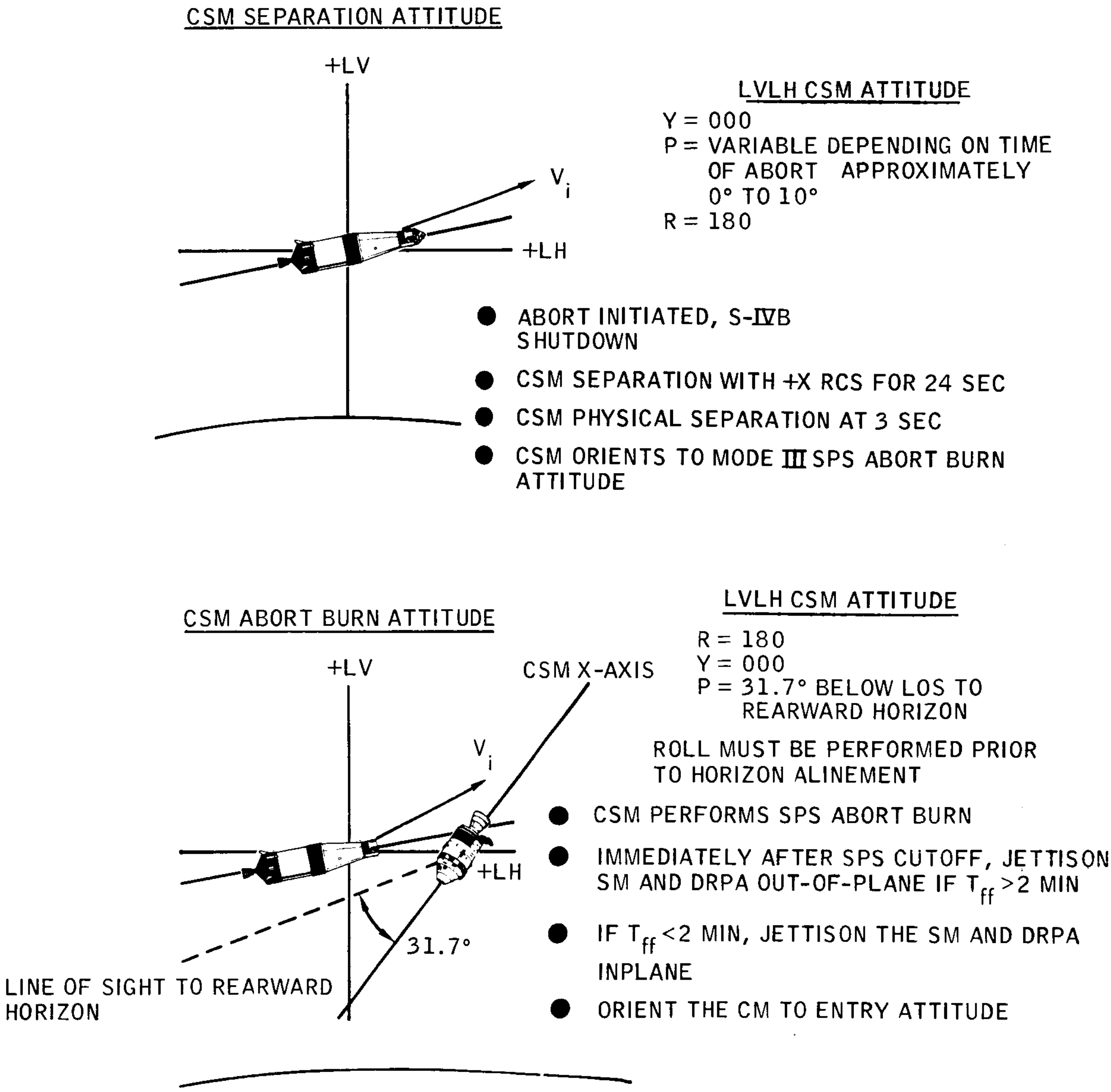


Figure 3.- Case: CSM separation from SLA/LM/S-IVB; condition: mode III abort.

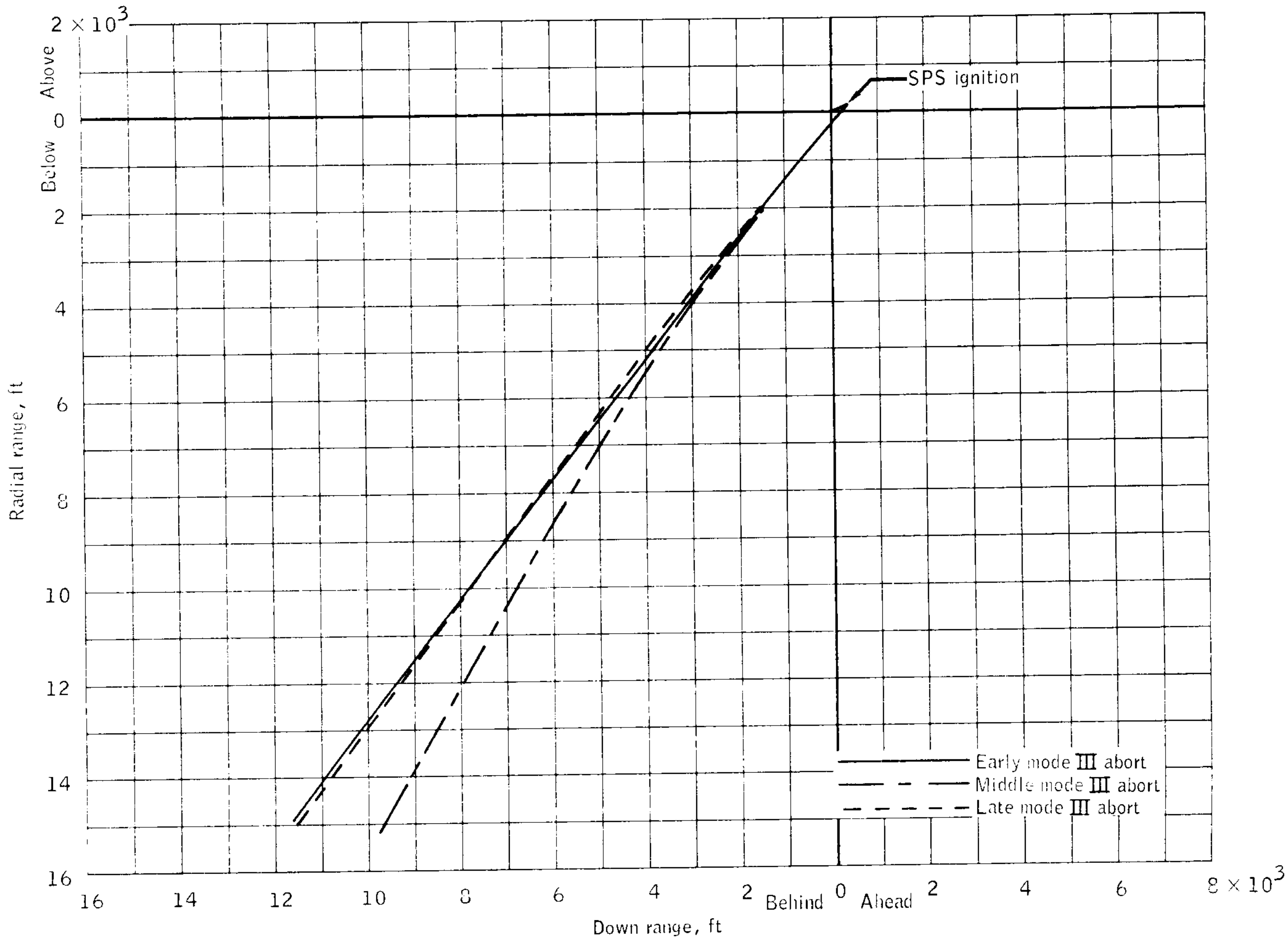


Figure 4.- Long range motion of the CSM relative to the S-IVB for mode III aborts.

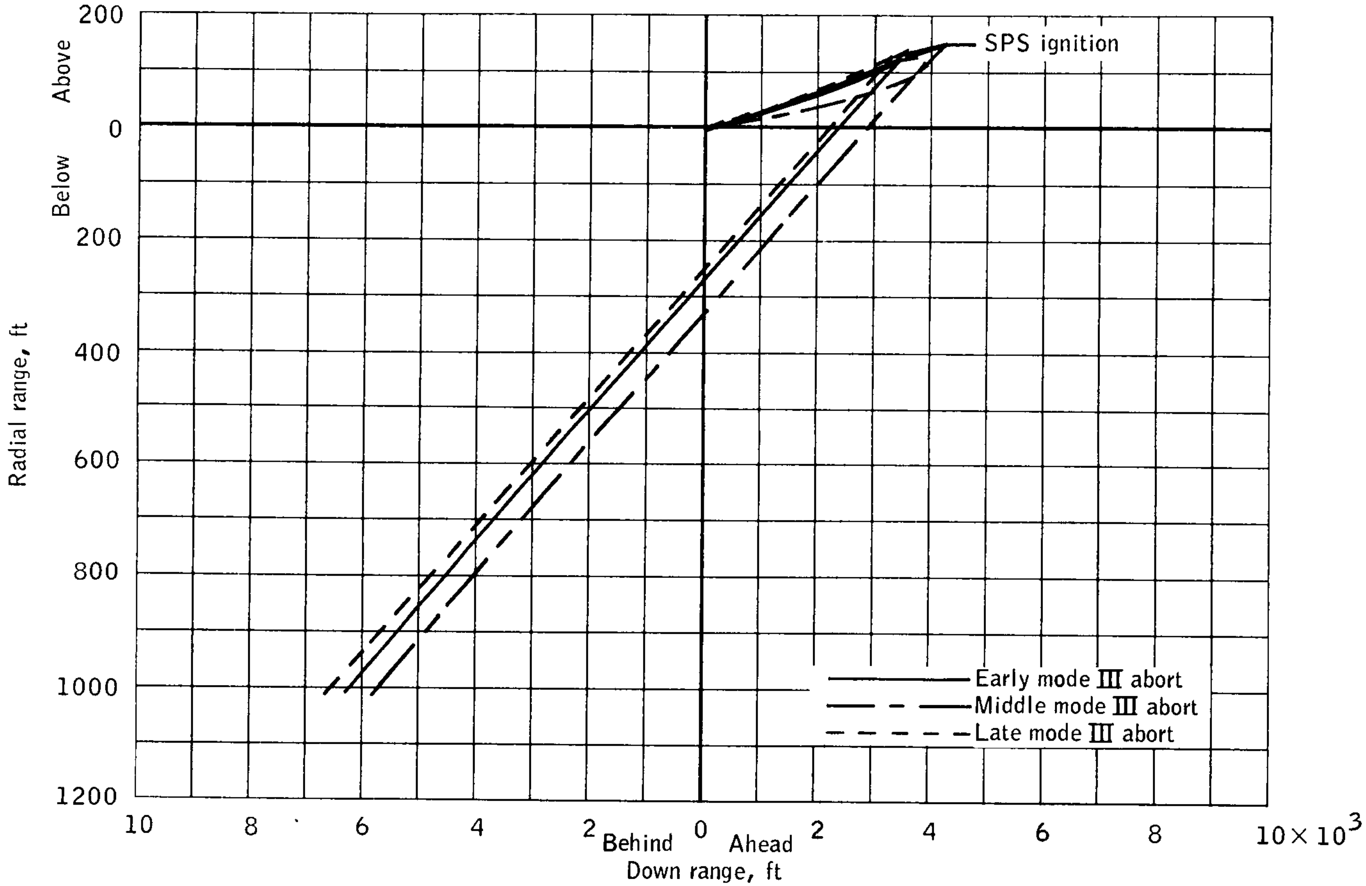
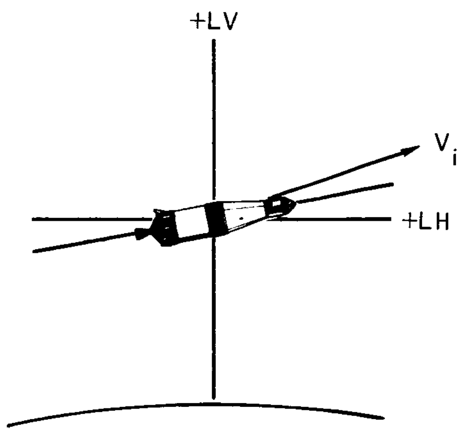


Figure 5.- Close-in motion of the CSM relative to the S-IVB for mode III aborts.

3.1.4 Contingency orbit insertions (COI) and apogee kick [begins when the SPS can insert the SC into a safe orbit (perigee altitude $\geq$ 75 n. mi.) and can deorbit the SC from any place in the resultant orbit. This capability begins when V_i = 22 220 fps (536 sec) and ends when the S-IVB has achieved a safe perigee 2 seconds prior to the nominal S-IVB cutoff signal (688 sec).] (figs. 6 and 7)

a. Abort is initiated; booster is cut off; and CSM +X RCS four-jet ullage is ON.
b. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.
c. Terminate CSM +X translation 24 seconds after abort initiation.
d. Orient to the mode IV COI attitude: CSM heads down, CSM +X-axis 31.7° above the LOS to the forward horizon; begin attitude hold and perform the required SOS COI burn.
e. For a description of detailed techniques available to the crew for performing COI, see reference 1.
f. CSM inserts into a contingency earth orbit.

CSM SEPARATION ATTITUDE

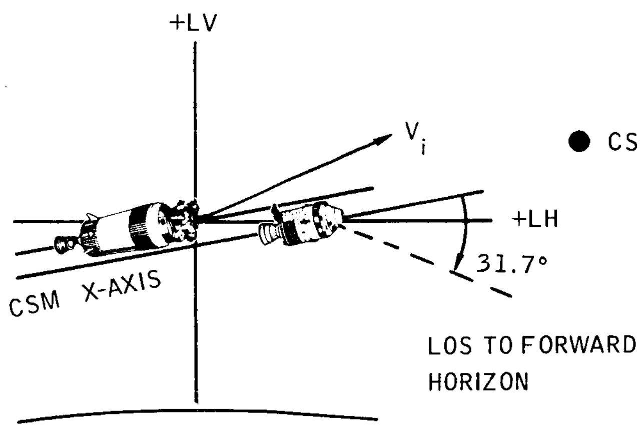


LVLH CSM ATTITUDE

Y = 000
P = VARIABLE
DEPENDING ON
TIME OF ABORT.
APPROXIMATELY
0 TO 10°
R = 180

- ABORT INITIATED S-IVB SHUTDOWN
- CSM SEPARATION WITH +X RCS FOR 24 SEC
- CSM PHYSICAL SEPARATION AT 3 SEC
- CSM ORIENTS TO COI BURN ATTITUDE

CSM COI BURN ATTITUDE



LVLH CSM ATTITUDE

R = 180
Y = 000
P = 31.7° ABOVE
LOS TO FORWARD
HORIZON

- CSM EXECUTES SPS COI BURN

Figure 6.- Case: CSM separation from SLA/LM/S-IVB; condition: mode IV abort, contingency orbit insertion.

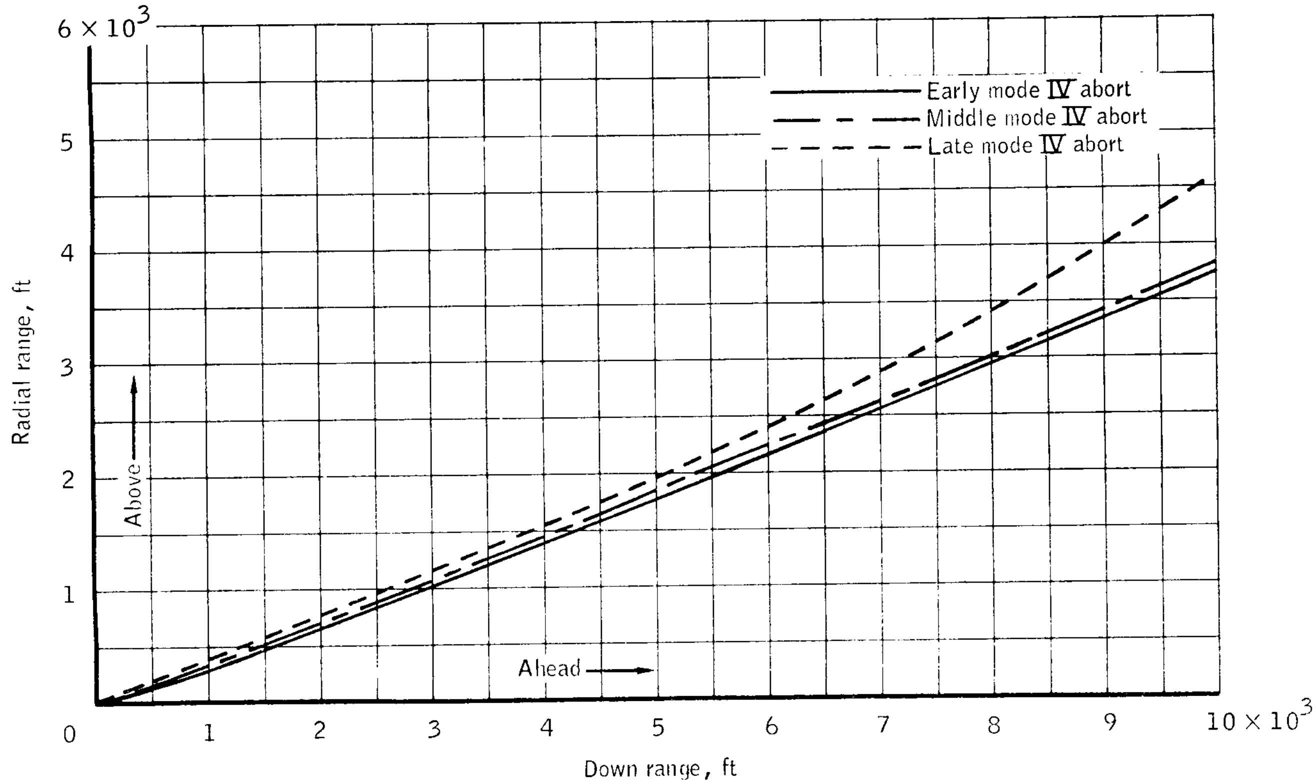
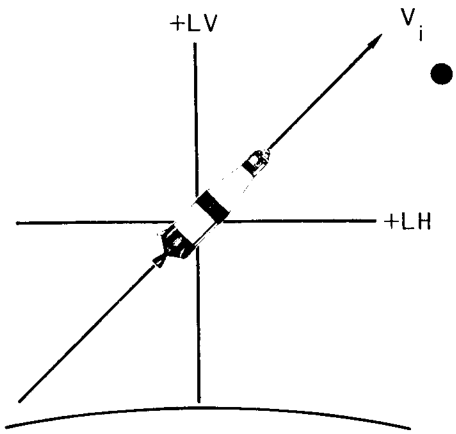


Figure 7.- Motion of the CSM relative to the S-IVB for mode IV aborts.

3.1.5 Launch phase abort, no SLA SEP (figs. 8, 9, and 10)

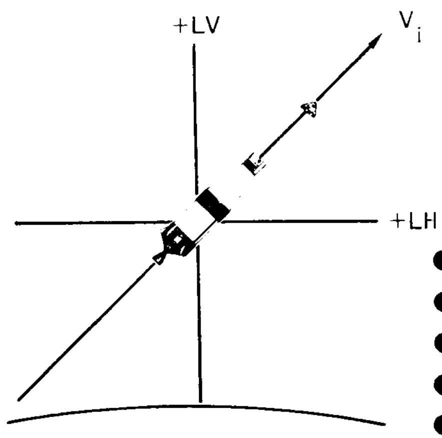
a. Abort is initiated; booster is cut off; CSM +X RCS four-jet ullage is ON.
b. At 3 seconds, SLA panels fail to separate; terminate CSM +X.
c. Perform CM jettison of the SM/SLA/S-IVB.
d. The SM -X RCS jets are ON for burn to fuel depletion after CM/SM SEP.
e. The CM orients to entry attitude (fig. 87).

CSM PERFORMS ABORT, SLA PANELS FAIL TO SEPARATE



- ABORT ATTITUDE IS CURRENT LAUNCH VEHICLE ATTITUDE DURING LAUNCH PHASE

CM JETTISONS SM/SLA/LM/S-IVB



- ABORT INITIATED, BOOSTER SHUT DOWN
- CSM +X RCS ON
- AT 3 SEC , SLA PANELS FAIL TO SEPARATE
- CSM TERMINATES +X
- CM SEPARATES, JETTISON SM/LM/S-IVB
- SM BURNS -X RCS TO FUEL DEPLETION
- CM ORIENTS TO ENTRY ATTITUDE

Figure 8.- Case: CM separation from the SM/SLA/LM/S-IVB; condition: no SLA separation during launch phase.

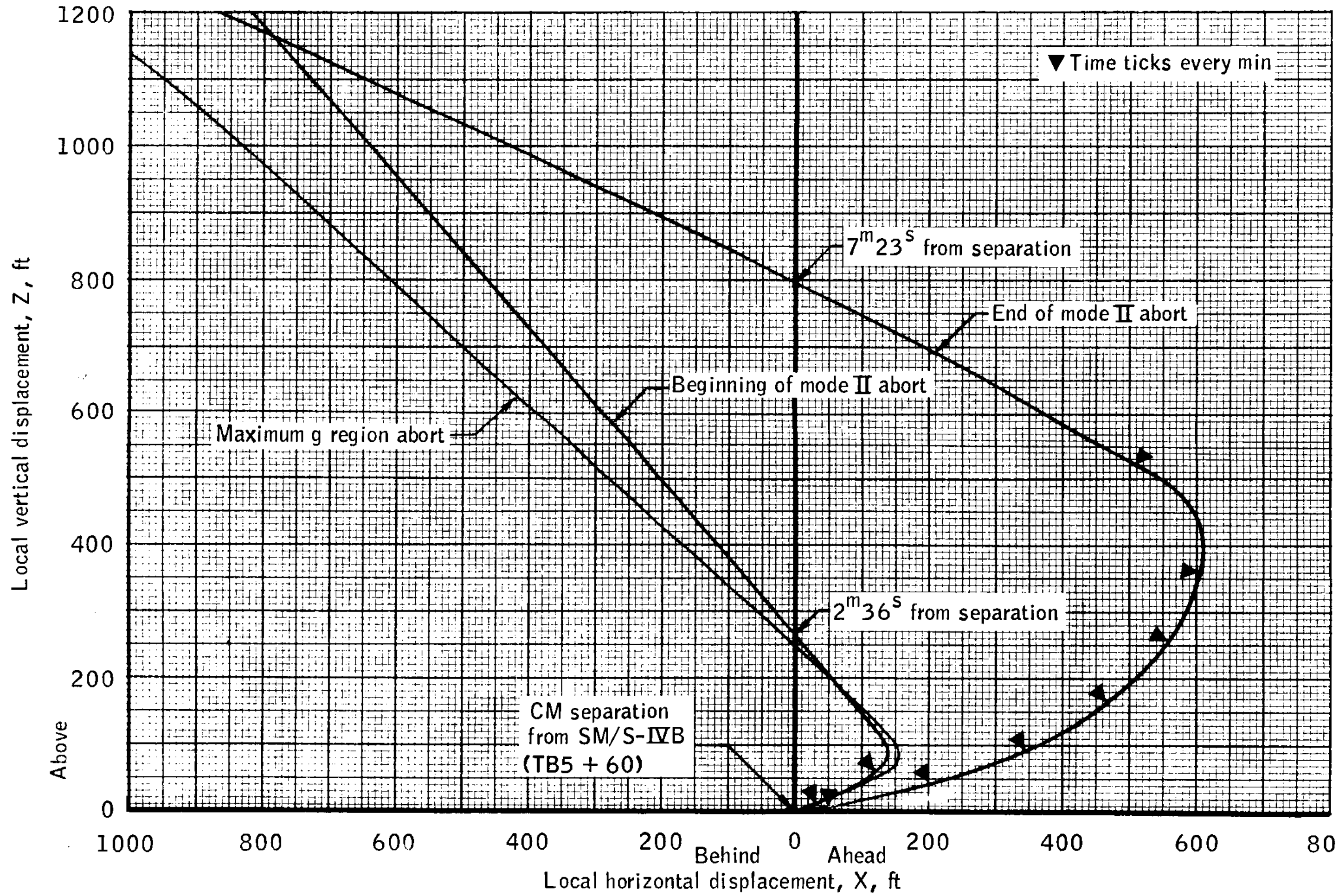


Figure 9.- Motion of the CM relative to the SM/S-IVB for no SLA separation during launch phase abort at maximum g region and the beginning and end of mode II.

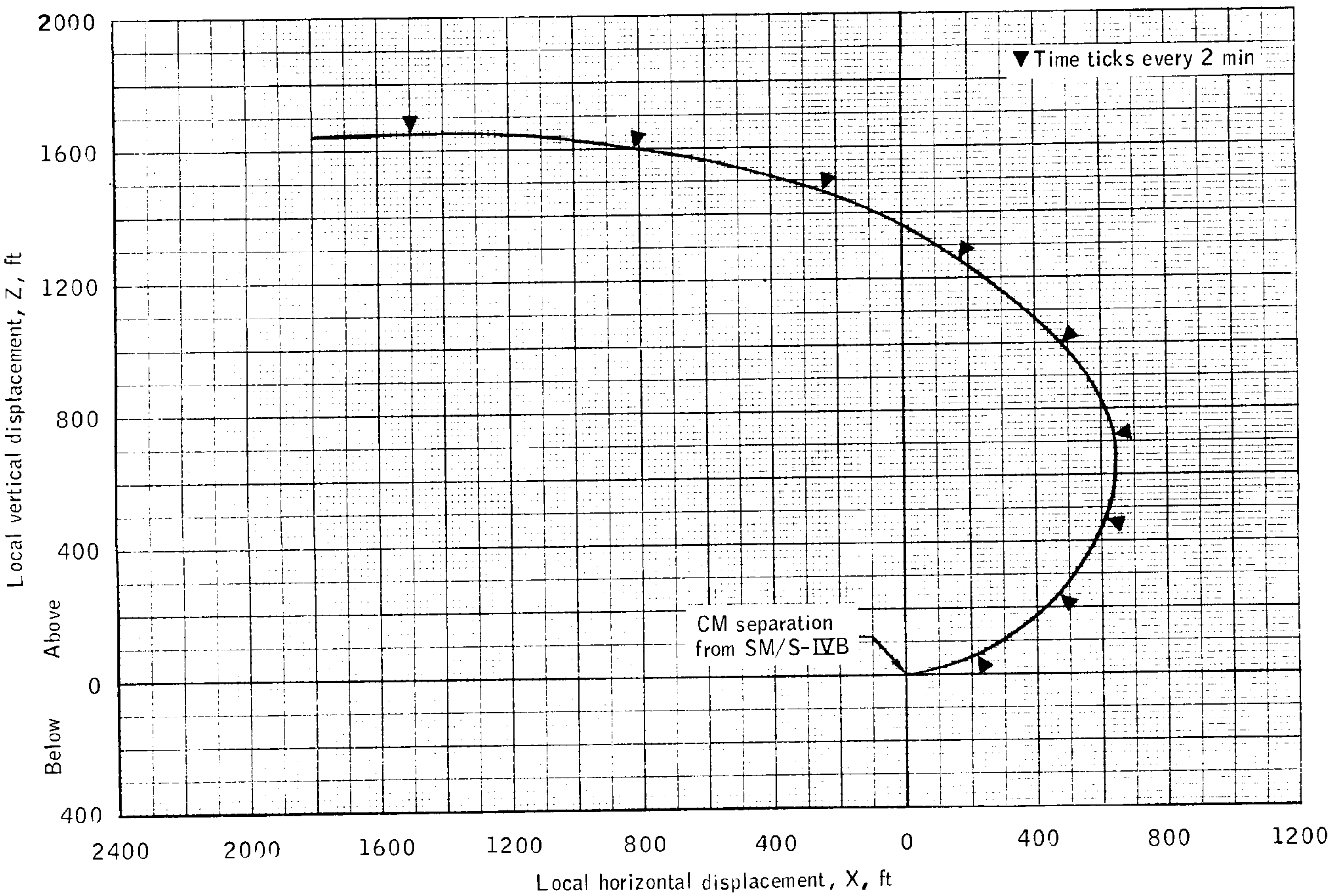


Figure 10.- Motion of the CM relative to the SM/S-IVB for no SLA separation during a launch phase abort at end of mode III region.

3.2 Aborts from a nonstable (tumbling) launch vehicle, launch phase (figs. 11 and 12)

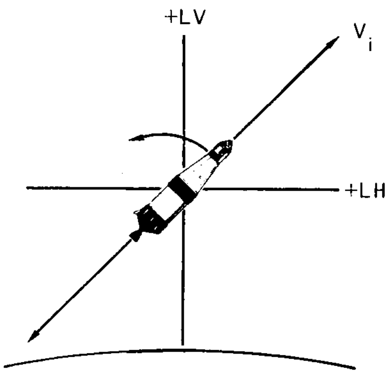
a. Abort is initiated; booster is cut off; and CSM +X RCS four-jet ullage is ON.

b. CSM/S-IVB physical separation occurs at 3 seconds after abort initiation; CSM +X ullage becomes RCS rate damping; SLA panels are jettisoned.

c. RCS rate damping continues until CSM rates are as follows.

1. For mode II, the rates must be low enough to permit jettison of the SM and DRPA and orientation to the CM entry attitude. The CM RCS can complete rate damping, if necessary.
2. For modes III and IV, the rates must be low enough to permit orientation to the proper abort burn attitude.
3. If time permits, the crew should try to establish that the S-IVB and the jettisoned SLA panels are not in the same direction as the abort burn because the SC can be located in any quadrant after a tumbling separation.

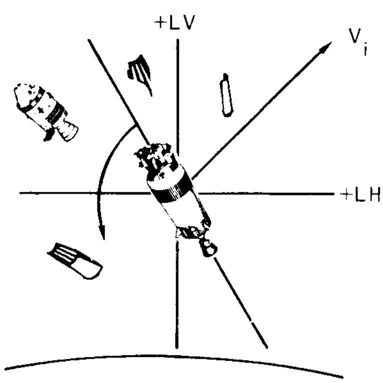
CSM SEPARATION FROM TUMBLING LAUNCH VEHICLE



- ABORT INITIATED, S-IVB SHUTDOWN
- CSM +X RCS ULLAGE BECOMES RCS RATE DAMPING AFTER PHYSICAL SEPARATION AT 3 SEC
- LAUNCH VEHICLE RATES IN PITCH AND YAW OF 14 DEG/SEC ARE ILLUSTRATED AND PRESENTED IN THE FOLLOWING RELATIVE MOTION

FOR MODE II ABORTS

- AFTER COMPLETION OF RATE DAMPING
  1. IF t_{ff} >2 MIN, YAW THE CSM +X AXIS 45° NORTH OUT-OF-PLANE AND JETTISON THE SM
  2. IF t_{ff} <2 MIN, JETTISON THE SM INPLANE
- ORIENT CM TO ENTRY ATTITUDE
- JETTISON DRPA



FOR MODE III AND IV ABORTS

- THE SC ORIENTS TO THE SPS ABORT BURN ATTITUDE
- FOR MODE III, IMMEDIATELY AFTER SPS CUTOFF
  1. IF t_{ff} >2 MIN, YAW THE CSM +X AXIS 45° SOUTH OUT-OF-PLANE AND JETTISON THE SM AND DRPA;
  2. IF t_{ff} <2 MIN, JETTISON THE SM AND DRPA INPLANE
  3. ORIENT CM TO ENTRY ATTITUDE
- FOR MODE IV, EXECUTE A COI

IF TIME PERMITS, THE CREW SHOULD TRY TO ESTABLISH THAT THE S-IVB AND JETTISONED SLA PANELS ARE NOT IN THE SAME DIRECTION AS THE ABORT BURN, AS THE SC CAN BE LOCATED IN ANY QUADRANT FOLLOWING A TUMBLING SEPARATION

Figure 11.- Case: CSM separation from SLA/LM/S-IVB; condition: aborts from a non-stable tumbling launch vehicle, launch phase.

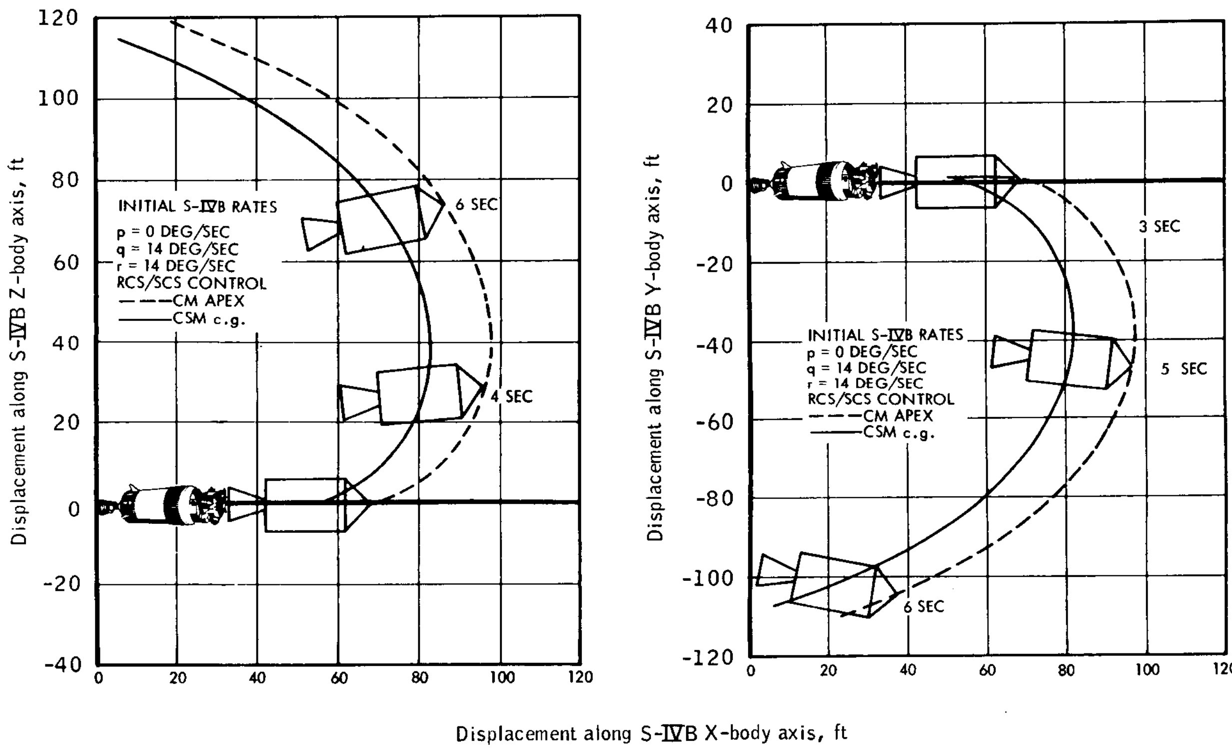


Figure 12.- Motion of the CSM relative to the S-IVB for RCS/SCS control, 14 deg/sec rates in pitch and yaw at separation.

4.0 EARTH ORBIT PHASE

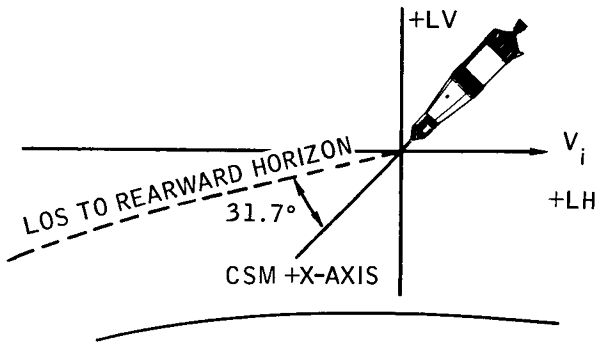
4.1 Aborts from earth orbit

4.1.1 CSM aborts from the SLA/LM/S-IVB

4.1.1.1 Primary abort procedure (retrograde attitude) (figs. 13 and 14)

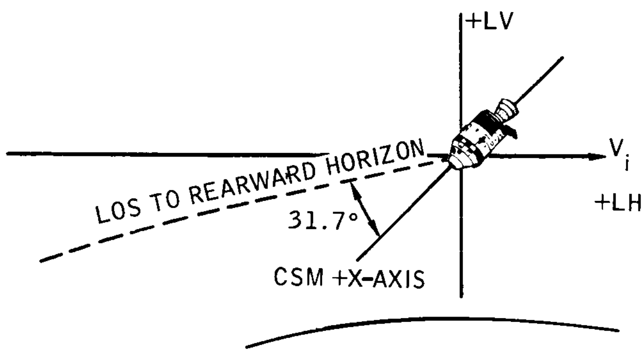
a. The crew manually orients the CSM/S-IVB configuration to the abort attitude: CSM heads-up, CSM +X-axis 31.7° below the LOS to the rearward horizon.
b. Abort is initiated; CSM +X RCS four-jet ullage is ON.
c. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage maneuvers become +X translations; SLA panels are jettisoned.
d. Terminate CSM +X translation 24 seconds after abort initiation; begin coast for 20 minutes.
e. Orient the CSM to the abort burn attitude: CSM heads up, +X-axis 31.7° below the LOS to the rearward horizon.
f. SPS ignition occurs at 20 minutes after abort initiation.
g. CSM SPS abort burn data will be ground computed.

CSM SEPARATION ATTITUDE



- CREW MANUALLY ORIENTS LAUNCH VEHICLE TO SEPARATION ATTITUDE
- CSM PERFORMS +X RCS FOR 24 SEC
- CSM PHYSICAL SEPARATION AT 3 SEC
- CSM ORIENTS TO DEORBIT BURN ATTITUDE

CSM DEORBIT BURN ATTITUDE



- CSM PERFORMS DEORBIT BURN 20 MIN AFTER SEPARATION

Figure 13.- Case: CSM separation from SLA/LM/S-IVB; condition: orbital abort - CSM aborts from SLA/LM/S-IVB in earth orbit, retrograde attitude (primary procedure).

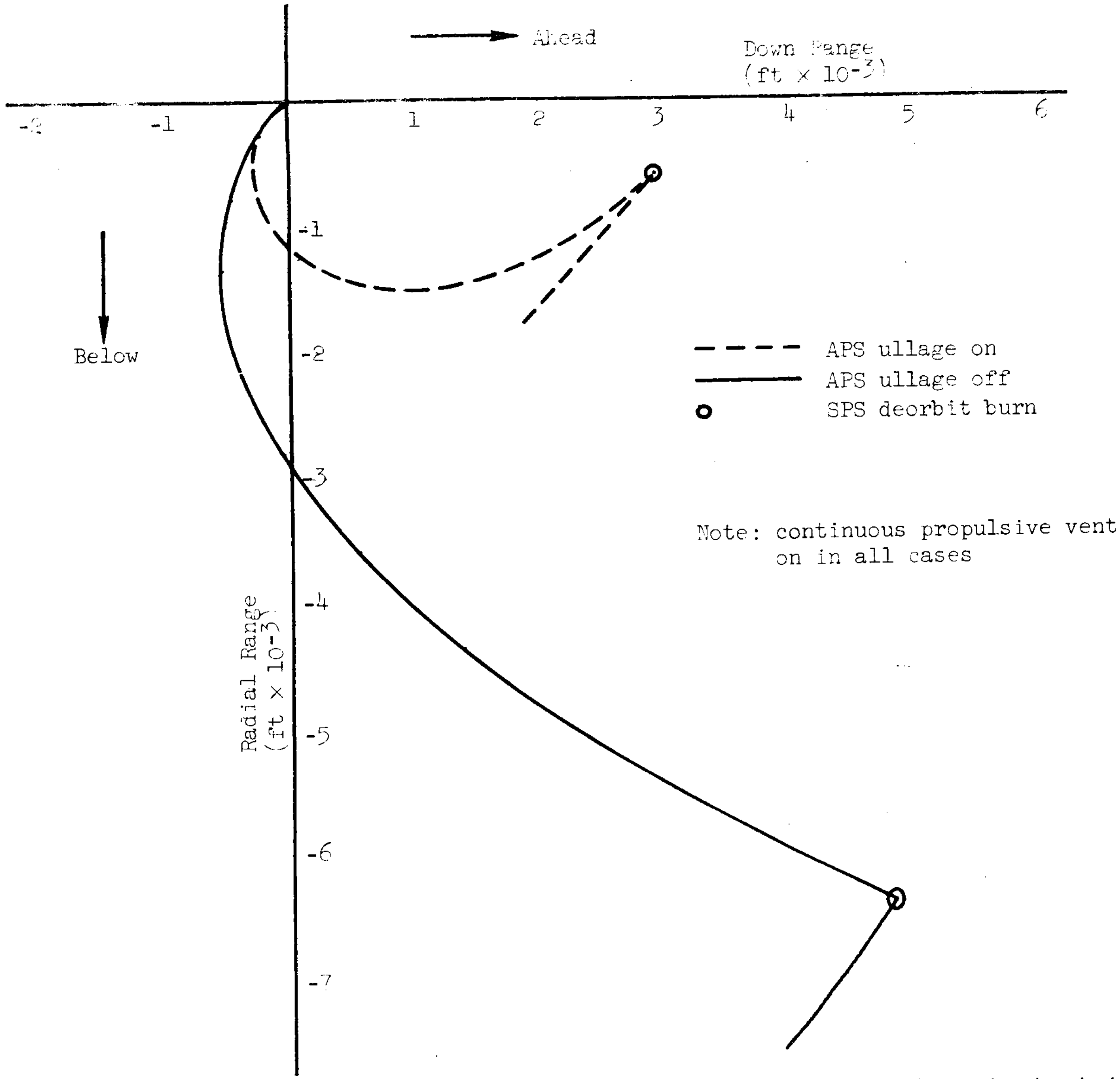


Figure 14.- Motion of the CSM relative to the S-IVB for retrograde earth orbital aborts.

4.1.1.2 Secondary abort procedure (posigrade attitude) (figs. 15 and 16)

a. If the crew cannot assume manual control of the S-IVB, the orbital abort will be performed with the CSM/S-IVB alined in the posigrade, LH attitude.

b. Abort is initiated; CSM +X RCS four-jet ullage is ON.

c. CSM/S-IVB physical separation occurs 3 seconds after abort initiation; CSM +X ullage becomes +X translation; SLA panels are jettisoned.

d. Terminate CSM +X translation 24 seconds after abort initiation; begin coast for 30 seconds.

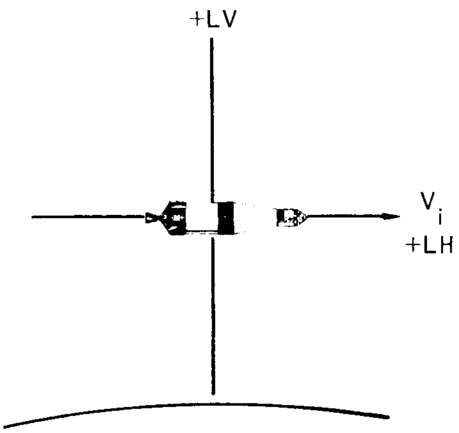
e. During the 30-second coast period, the CSM orients to a heads-up attitude and alines the +X-axis 31.7° below the LOS to the rearward horizon.

f. At 54 seconds after abort initiation, perform CSM +X RCS translation for 30 seconds.

g. Orient to the SPS abort burn attitude: CSM heads up, +X-axis 31.7° below the LOS to the rearward horizon.

h. SPS ignition occurs at 20 minutes after abort initiation.

CSM SEPARATION ATTITUDE

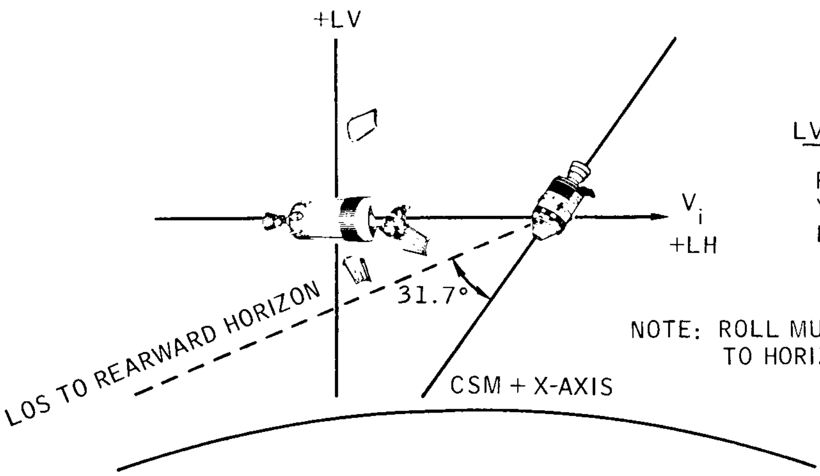


LVLH CSM ATTITUDE

Y = 000
P = 000
R = 000/180

- CREW CANNOT TAKE MANUAL CONTROL OF S-IVB; ABORT IS PERFORMED IN CURRENT ATTITUDE
- CSM PERFORMS +X RCS FOR 24 SEC
- CSM PHYSICAL SEPARATION AT 3 SEC
- CSM ORIENTS TO REARWARD HORIZON MONITOR ATTITUDE SHOWN BELOW

CSM 30 SEC RCS MANEUVER ATTITUDE



LVLH CSM ATTITUDE

R = 180
Y = 000
P = 31.7° BELOW LOS TO REARWARD HORIZON

NOTE: ROLL MUST BE PERFORMED PRIOR TO HORIZON ALINEMENT

- CSM PERFORMS +X RCS FOR 30 SEC
- SPS IGNITION FOR DEORBIT BURN AT 20 MIN AFTER SEPARATION (SAME ATTITUDE AS ABOVE)

Figure 15.- Case: CSM separation from the SLA/LM/S-IVB; condition: abort - CSM aborts from the SLA/LM/S-IVB during earth orbit, posigrade attitude (secondary procedure).

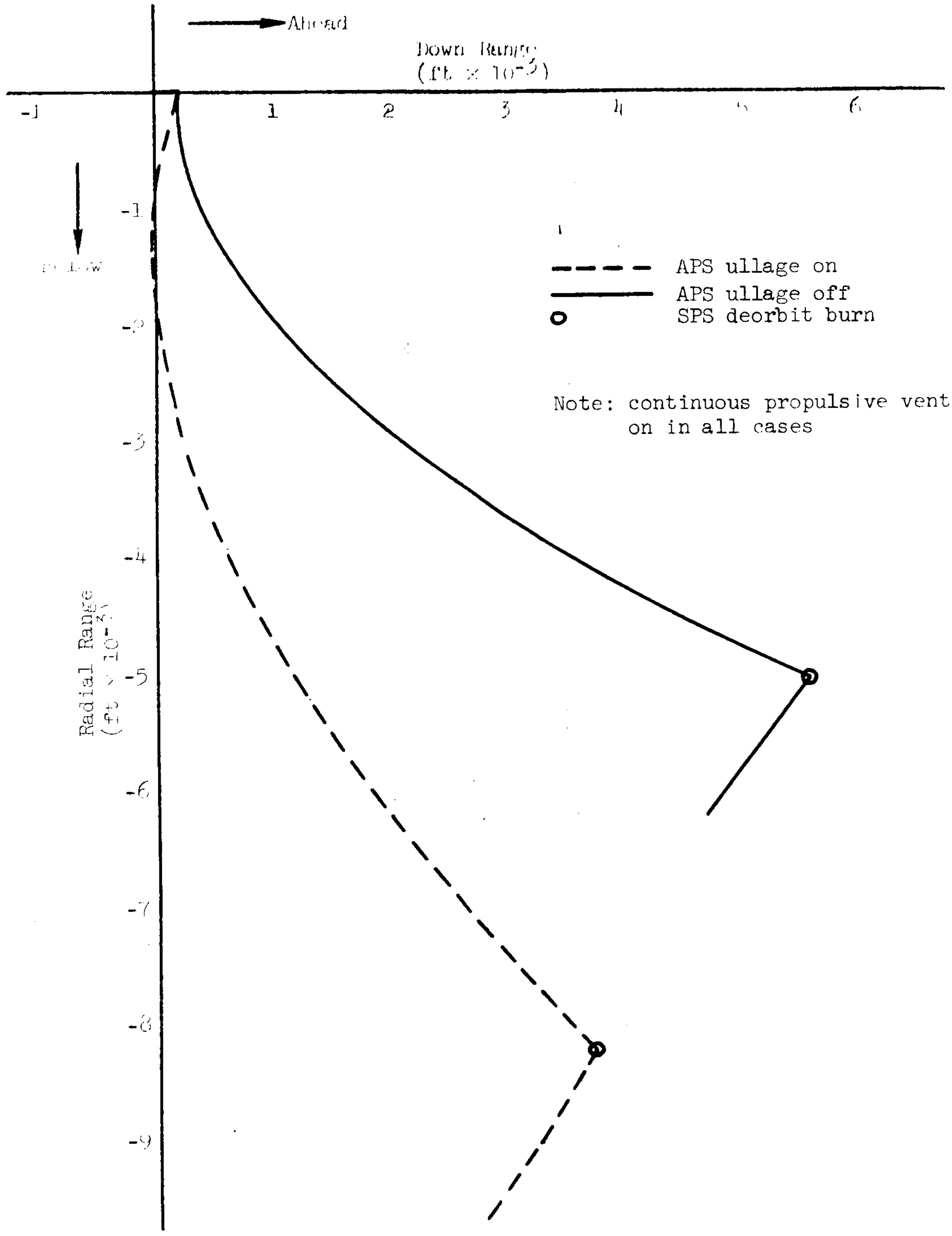


Figure 16.- Motion of the CSM relative to the S-IVB for posigrade earth orbital aborts.

4.1.2 CSM docked, aborts from the LM/S-IVB during earth orbit alternate mission (figs. 17 and 18)

a. The CSM/S-IVB docked configuration is alined with the LH, CSM +X-axis retrograde.

b. Abort is initiated; CSM jettisons the LM/S-IVB (the DRPA remains with the LM) and performs -X RCS translation for 24 seconds.

c. The CSM orients to a heads-up attitude with the +X-axis alined 31.7° below the LOS to the rearward horizon and initiates +X RCS translation for 30 seconds.

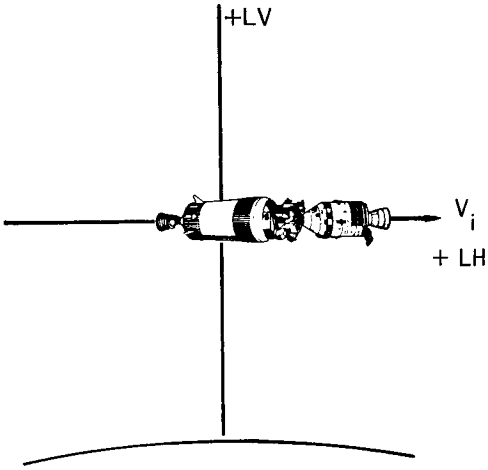
d. The CSM orients to the deorbit burn attitude: heads up, +X-axis 31.7° below LOS to rearward horizon.

e. SPS ignition occurs at 20 minutes after abort initiation.

CSM ABORT ATTITUDE

LVLH CSM ATTITUDE

Y = 000
P = 180
R = 000



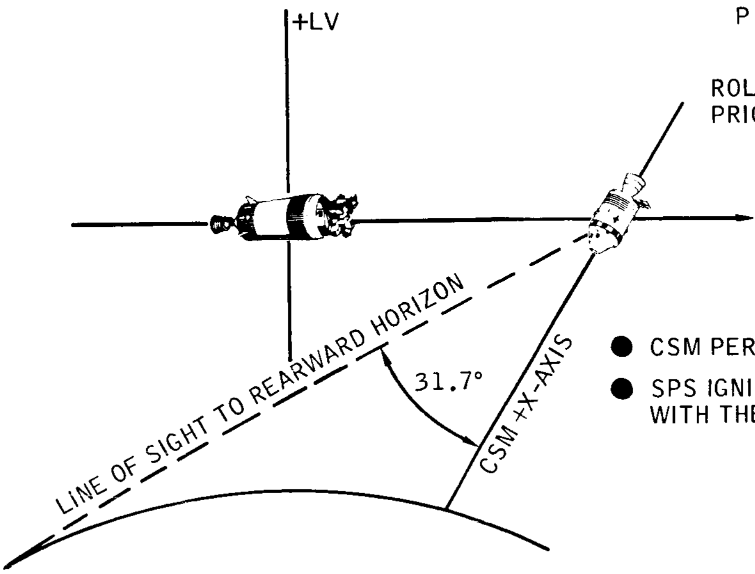
- CSM JETTISONS LM
- CSM PERFORMS -X RCS FOR 24 SEC
- CSM ORIENTS TO HEADS-UP REARWARD HORIZON ATTITUDE SHOWN BELOW

CSM ATTITUDE FOR 30-SEC RCS BURN

LVLH CSM ATTITUDE

R = 180°
Y = 000
P = 31.7° BELOW LOS TO
REARWARD HORIZON

ROLL MUST BE PERFORMED
PRIOR TO HORIZON ALINEMENT



- CSM PERFORMS +X RCS FOR 30 SEC
- SPS IGNITION OCCURS 20 MIN LATER WITH THE CSM IN THIS SAME ATTITUDE

Figure 17.- Case: CSM separates from LM/S-IVB; condition: abort - CSM is docked to LM/S-IVB in earth orbit and separates for deorbit.

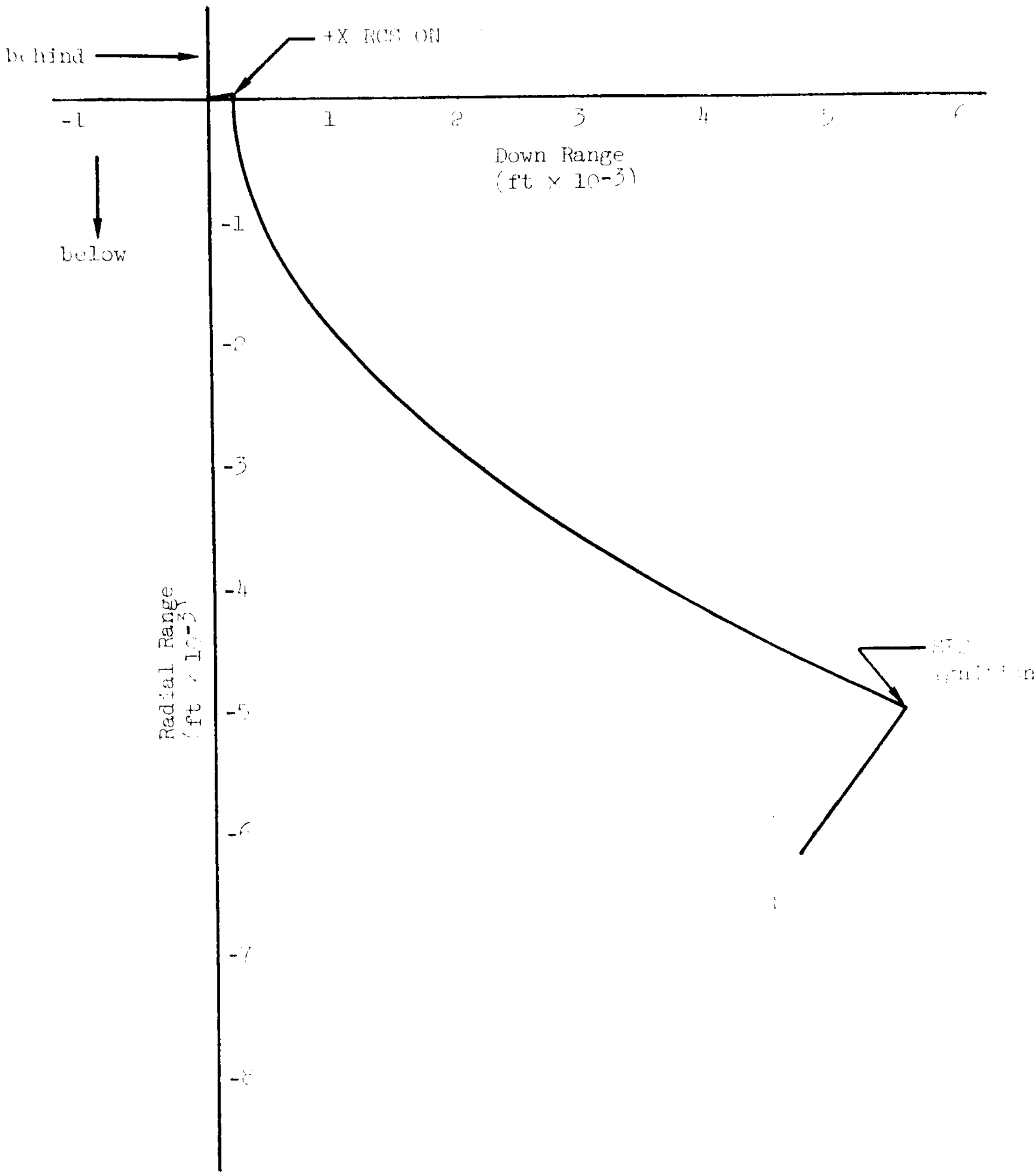


Figure 18.- Motion of the CSM relative to the S-IVB for earth orbital aborts while docked to the LM/S-IVB.

4.1.3 CSM aborts from the LM during earth orbit alternate mission (figs. 19 and 20)

a. After the LM is configured for jettison, the crew orients the CSM to a posigrade, heads-down attitude and alines the CSM +X-axis 31.7° above the LOS to the forward horizon.

b. Abort is initiated; the CSM jettisons the LM (the DRPA remains with the LM) and performs -X RCS translation for 24 seconds.

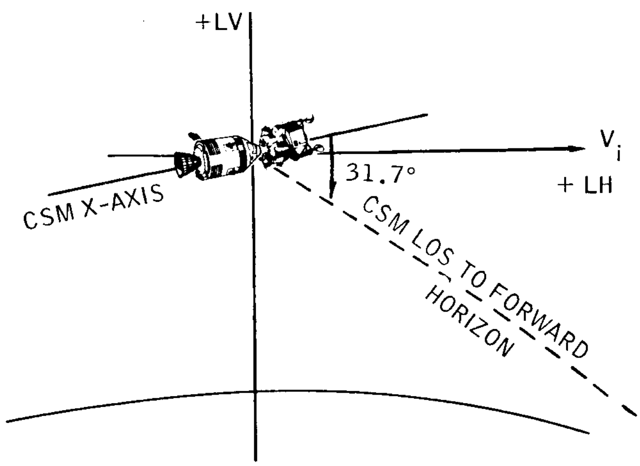
c. The CSM then orients to the abort burn attitude: CSM heads up, +X-axis 31.7° below the LOS to the rearward horizon.

d. SPS ignition occurs at 20 minutes after abort initiation.

e. CM/SM separation

1. CSM remains in the deorbit burn attitude.
2. Yaw the CSM +X-axis 45° north out of plane.
3. Jettison the SM.
4. Orient to the CM entry attitude.

CSM/LM SEPARATION ATTITUDE



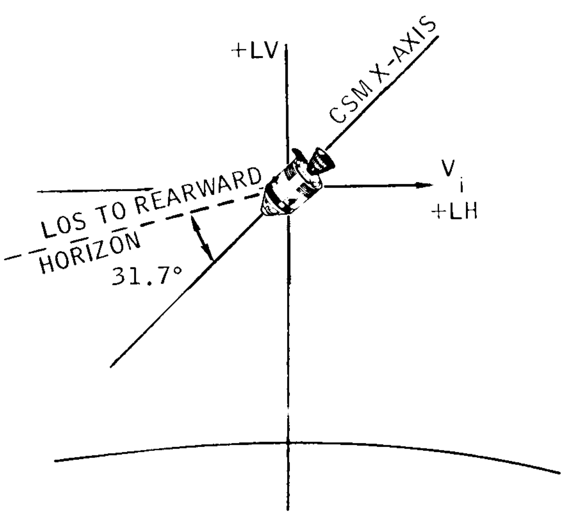
LVLH CSM ATTITUDE

R = 180
Y = 000
P = 31.7° ABOVE LOS TO
FORWARD HORIZON

ROLL MUST BE PERFORMED
PRIOR TO HORIZON ALINEMENT

- CREW CONFIGURES THE LM FOR JETTISON
- CSM ORIENTS TO JETTISON ATTITUDE
- EXECUTE LM JETTISON AND PERFORM CSM -X RCS FOR 24 SEC

CSM DEORBIT BURN ATTITUDE



LVLH CSM ATTITUDE

R = 180
Y = 000
P = 31.7° BELOW LOS TO
REARWARD HORIZON

ROLL MUST BE PERFORMED
PRIOR TO HORIZON ALINEMENT

- CSM ORIENTS TO DEORBIT BURN ATTITUDE
- SPS IGNITION OCCURS AT 20 MIN AFTER SEPARATION

Figure 19.- Case: CSM separate from LM; condition: abort - CSM is docked to LM during earth orbit alternate mission and separates for deorbit.

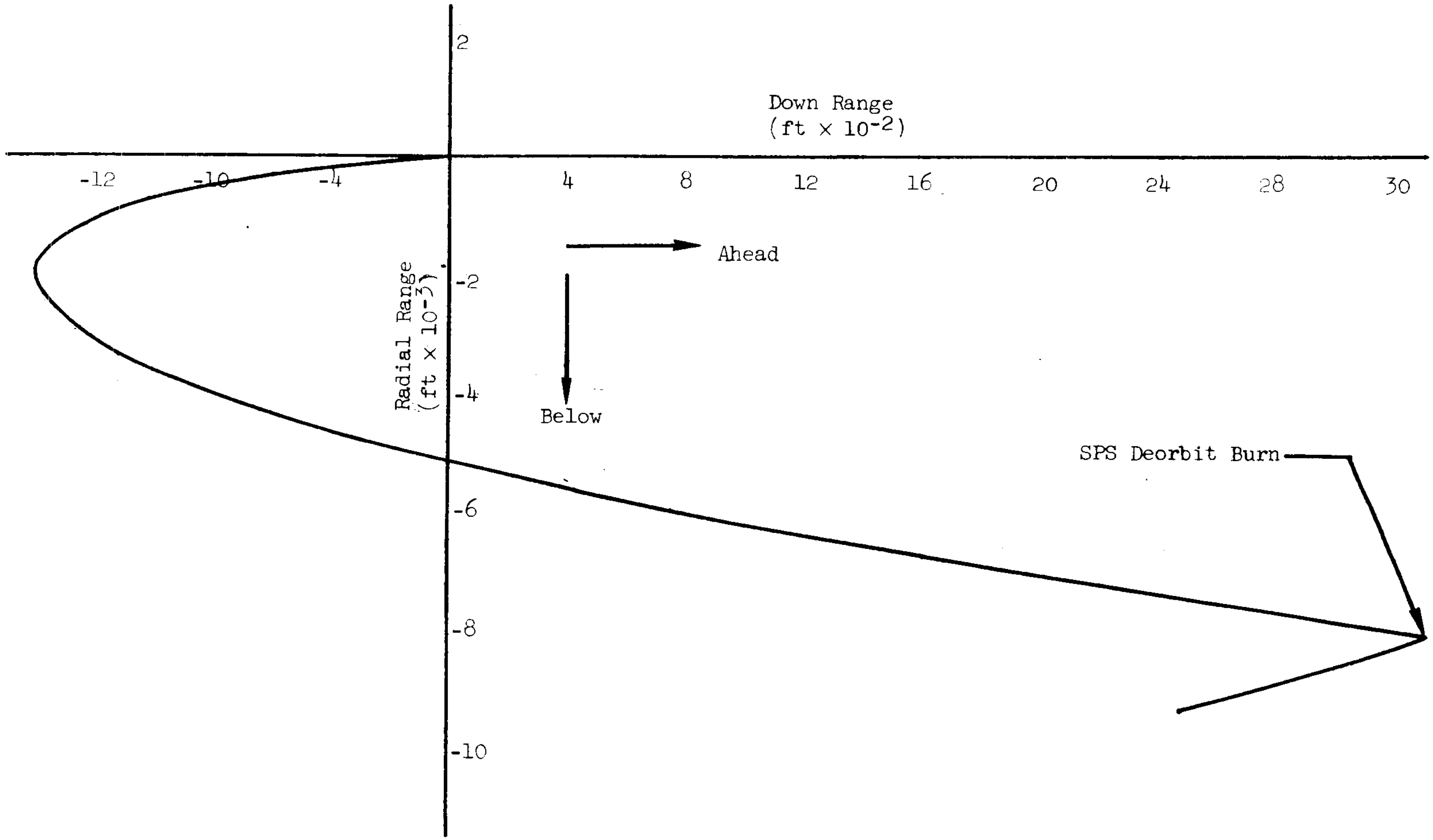
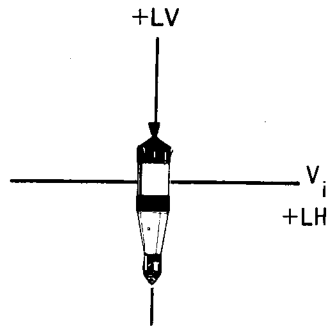


Figure 20.- Motion of the CSM relative to the LM for earth orbital aborts initiated while docked with the LM.

4.1.4 No SLA SEP during earth orbit abort or alternate mission (figs. 21 and 22)

a. SLA panels fail to separate; CM abort is required.
b. Using an S-IVB propellant dump, lower perigee to 80 n. mi. (procedure described in ref. 2).
c. For CM separation, either of the following attitudes may be used.
   1. The launch vehicle remains in the dump attitude: the CSM/S-IVB +X-axis is alined with the retrograde local horizontal. (Relative motion and illustrations are not available for this case; however, no recontact problems are apparent.)
   2. The crew manually alines the launch vehicle with the negative radius vector; CM apex is toward earth. (Relative motion and illustrations are presented for this case.)
d. Initiate CM separation.
e. The SM will perform -X RCS translation for a burn to fuel depletion.
f. Initiate CM RCS deorbit <u>11</u> minutes after separation.
g. The recommended attitude (ref. 3) for CM RCS thrusting is to position the CM +X-axis 71.5° below the positive local horizontal and the +Z-axis inplane directed toward the earth (heads-up attitude). Both CM RCS systems are fired simultaneously for the deorbit maneuver. The negative pitch engines are fired continuously, and the positive pitch engines are pulsed to null the resultant moments. (for more detailed data on CM RCS deorbit techniques, see ref. 3.)
h. Terminate CM RCS deorbit burn at an effective ΔV = <u>72.7</u> fps. (Maximum ΔV available is 80 fps for a CM weight of 12 300 lbs.)

CM SEPARATION ATTITUDE

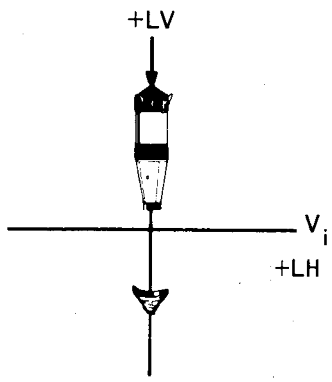


LVLH SC ATTITUDE

Y = 000
P = -090
R = 000/180

- SLA PANELS FAIL TO SEPARATE
- S-IVB PROPELLANT DUMP LOWERS PERIGEE TO 80 N. MI.
- LAUNCH VEHICLE ORIENTS TO SEPARATION ATTITUDE (SEE TEXT ON PROCEDING PAGE FOR DEFINITION OF ATTITUDE)

CM SEPARATION



- CM JETTISON LAUNCH VEHICLE
- SM -X RCS BURN TO FUEL DEPLETION
- CM RCS DEORBIT BEGINS 11 MIN AFTER SEPARATION
- RCS BURN TIME IS APPROXIMATELY 98 SEC, EFFECTIVE ΔV = 72.7 FPS

Figure 21.- Case: CM separation from SM/SLA/LM/S-IVB; condition: no SLA separation during earth orbit abort.

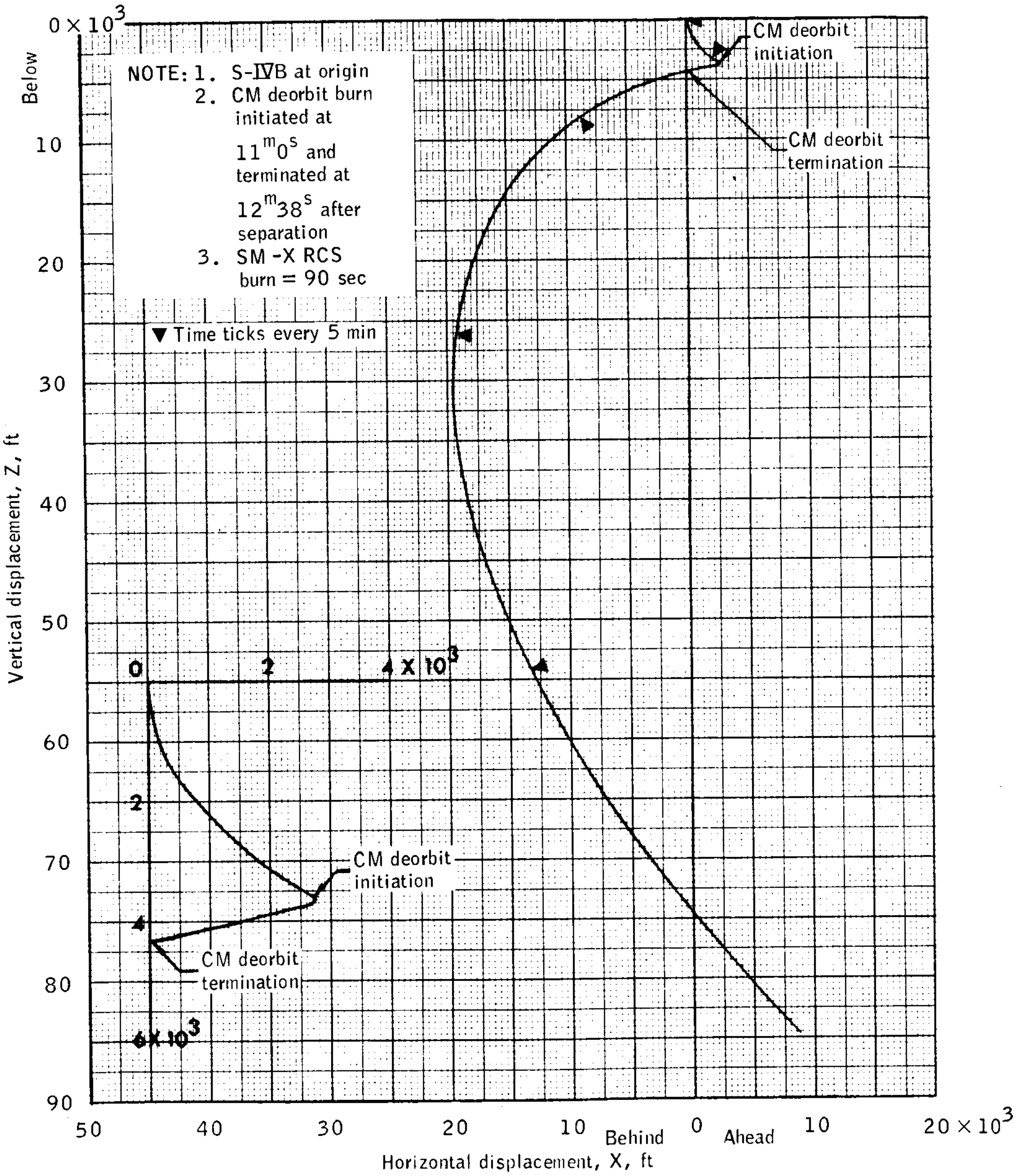


Figure 22.- CM relative motion with respect to the S-IVB for no SLA separation during earth orbit.

4.1.5 Emergency SEP procedure for an impending, detectable S-IVB explosion prior to nominal CSM/S-IVB separation (figs. 23, 24, and 25)

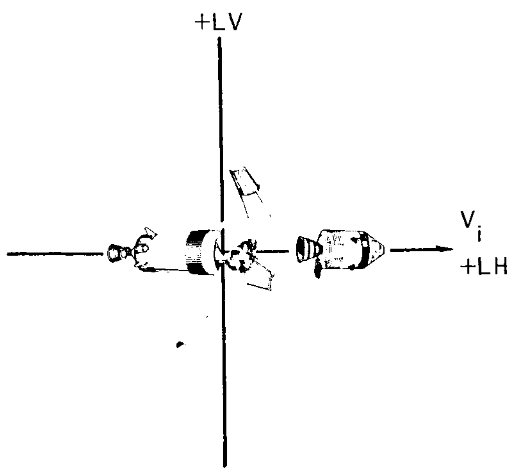
a. Warning is received; abort is initiated; S-IVB is shut down (if thrusting); initiate CSM +X RCS.

b. CSM/S-IVB physical separation at 3 seconds; continue RCS +X translation.

c. At 3 seconds after separation (6 sec after abort initiation), terminate RCS +X and perform a 5-second SPS burn. (No attitude orientation is required for the SPS burn.) For a CSM weight of 63 700 lb, a 5-second SPS burn would yield a ΔV of approximately 50 fps.

d. The CSM will achieve a range of 7080 feet within 140 seconds. For a warning time of 200 seconds, a separation delay of up to 60 seconds could be tolerated.

CSM/S-IVB SEPARATION ATTITUDE



LVLH SC ATTITUDE

NOTE: EMERGENCY SEPARATION ATTITUDE IS THE CURRENT LAUNCH VEHICLE ATTITUDE

- WARNING RECEIVED
- S-IVB SHUT DOWN (IF THRUSTING)
- CSM PERFORMS +X RCS FOR 6 SEC
- PHYSICAL SEPARATION OCCURS AT 3 SEC
- CSM PERFORMS 5-SEC SPS BURN IMMEDIATELY AFTER RCS BURN

CSM/S-IVB SEPARATION

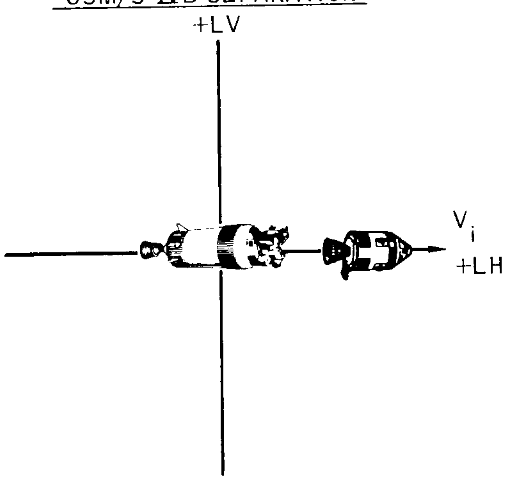


Figure 23.- Case: CSM separation from the SLA/LM/S-IVB; condition: emergency separation because of an impending S-IVB explosion, earth orbit.

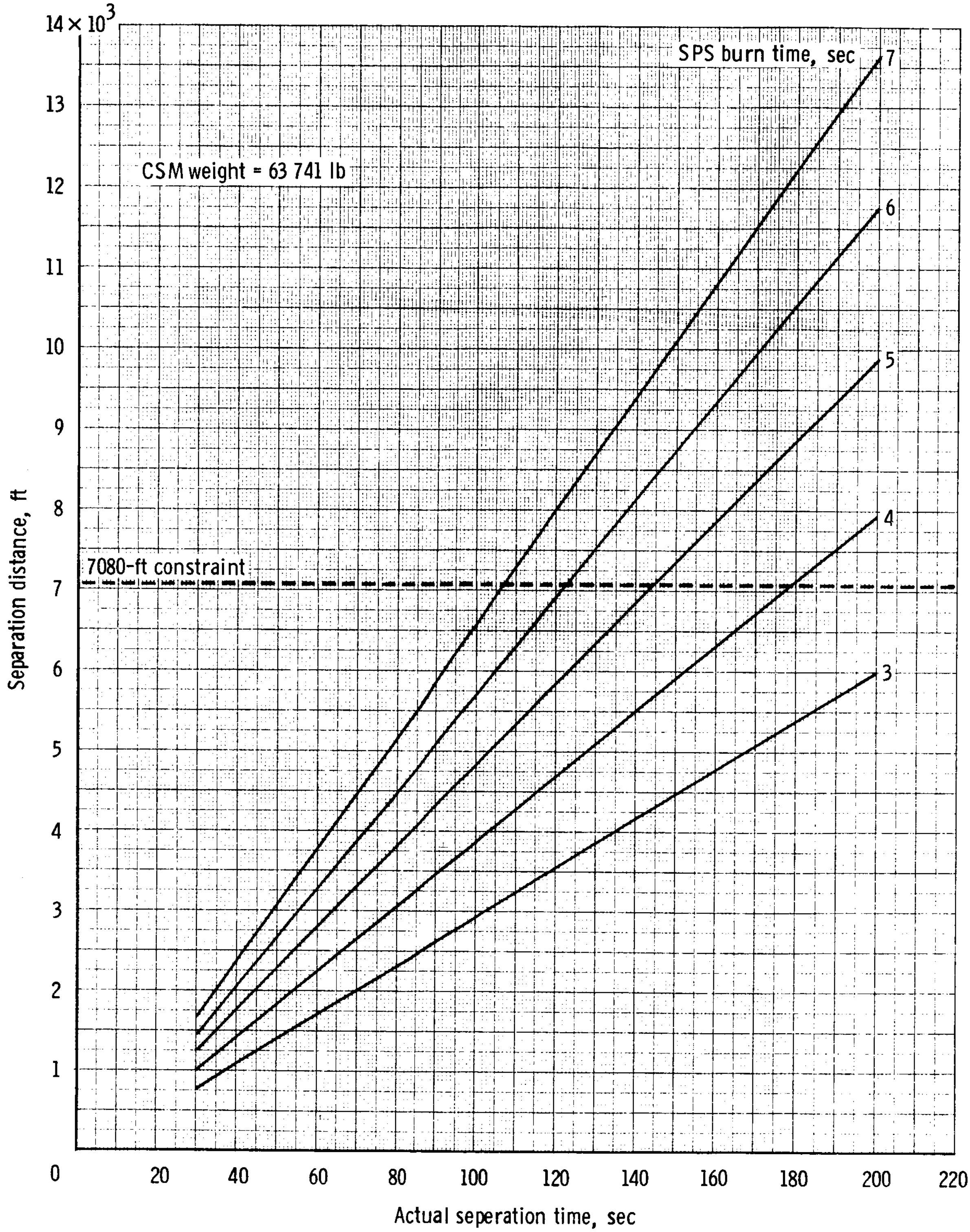


Figure 24. - CSM/S-IVB separation distance versus actual separation time for an impending S-IVB explosion.

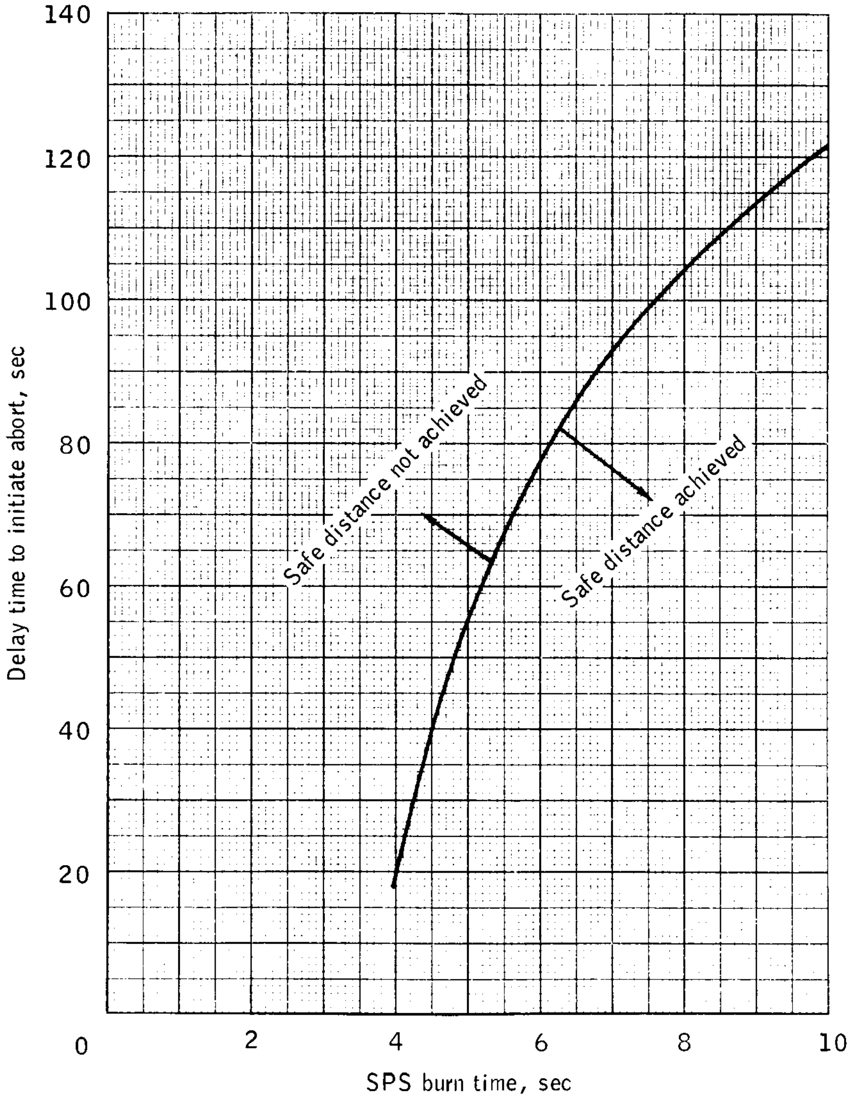


Figure 25.- SPS burn time versus delay time to initiate an abort subsequent to the warning.

4.1.6 Emergency separation procedure for an unsafe LM; CSM jettisons entire LM.

Time after warning is received, min:sec	Event
00:00	Warning received; SM RCS -X ON; jettison LM
00:06	RCS OFF; begin orientation to SPS burn attitude[a]
01:05	End orientation as soon as possible; SPS ON
01:12	SPS OFF; burn Δt = 7 seconds, ΔV = 70 fps
02:49	Safe distance achieved for a CSM weight of 64 000 pounds
03:20	LM destruction occurrs

[a]The performance by the crew of a 60° pitch maneuver (about the CSM Y-axis) is suggested to attain the SPS burn attitude. The burn attitude must not cause the CSM to deorbit. This procedure assumes that a warning time of 200 seconds is provided and that a safe separation distance is at least 7080 feet.

4.1.7 Emergency separation procedure for unsafe LM descent stage; CSM/LM ascent jettisons the descent stage.

Time after warning is received, min:sec	Event
00:00	Warning received; SM RCS -X ON; jettison LM descent stage
00:06	RCS OFF; begin orientation to the SPS burn attitude[a]
01:05	End orientation as soon as possible; SPS ON
01:12	SPS OFF; burn Δt = 7 seconds, ΔV = 60 fps
03:09	Safe distance achieved for a CSM/LM ascent stage weight of 75 000 pounds
03:20	LM descent stage destruction occurs

[a]The performance by the crew of a 60° pitch maneuver (about the CSM X axis) is suggested to attain the SPS burn attitude. The burn attitude must not cause the CSM/LM ascent stage to deorbit. This procedure assumes that a warning time of 200 seconds is provided and that a safe separation distance is at least 7080 feet.

4.2 Earth orbit alternate missions

4.2.1 CSM separation from the S-IVB, T&D during earth orbit (figs. 26 and 27)

a. Prior to separation, the S-IVB orients to and holds the nominal T, D, and E attitude.

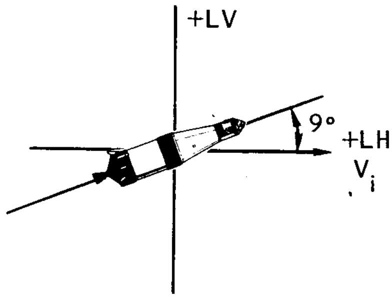
b. The CSM separates from the S-IVB, and SLA panels are jettisoned approximately 85 minutes prior to ejection. CSM separation can be performed at $2^h41^m00^s$ or $4^h06^m00^s$ g.e.t. T&D is completed during the subsequent daylight pass. CSM/LM ejection is performed at the beginning of the next daylight pass at $4^h06^m00^s$ or $5^h31^m00^s$ g.e.t.

c. CSM separation ΔV = 0.8 fps.

d. The remaining T&D timeline is the same as nominal T&D (section 6.1.1) and is as follows.

   1. Thirty-five seconds after separation, perform CSM -X RCS to null 0.3-fps separation rate.
   2. Initiate CSM pitch of 180° at 1.5 deg/sec rate.
   3. Null pitch rate and roll CSM left 60° at 0.5 deg/sec.
   4. Null the roll rate. Perform CSM +X RCS to null the remaining separation rate and to establish a 1.0-fps closing rate, 4^m40^s after separation.
   5. Null the closing rate and perform docking approximately 9^m35^s after separation.

CSM/S-IVB SEPARATION ATTITUDE AT 2:41:00 G.E.T., 85 MIN PRIOR TO EJECTION AT 4:06:00 G.E.T.



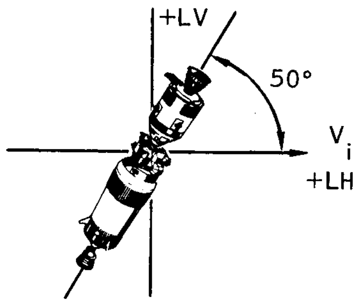
CSM GIMBALS

R (OGA) = 356.0
P (MGA) = 092.0
Y (IGA) = 331.7
PAD REFSMMAT (ref. 4)

LVLH CSM ATTITUDE

Y = -028.7
P = 008.0
R = -002.5

CSM DOCKS WITH LM AT 2:51:00 G.E.T.



LVLH SC ATTITUDE

Y = 140.0
P = -042.3
R = 122.5

- CSM SEPARATION PERFORMED IN THE NOMINAL INERTIAL T, D, AND E ATTITUDE APPROXIMATELY 85 MIN PRIOR TO EJECTION
- CSM PERFORMS +X RCS FOR ΔV = 0.8 FPS
- CSM NULLS 0.5 FPS, PITCHES 180°, AND NULLS 0.3 FPS
- CSM ESTABLISHES 1.0-FPS CLOSING RATE
- CSM BEGINS DOCKING APPROXIMATELY 10 MIN AFTER SEPARATION

Figure 26.- Case: CSM/S-IVB separation; condition: alternate mission, T and D during earth orbit.

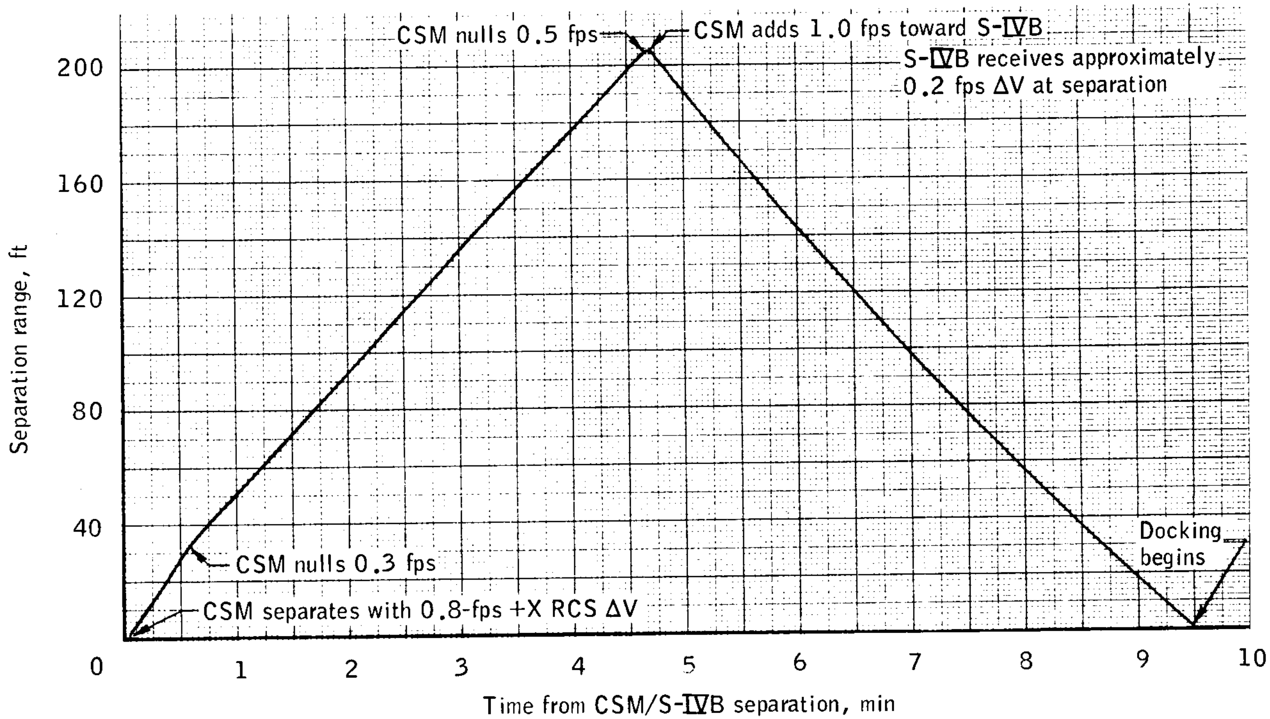
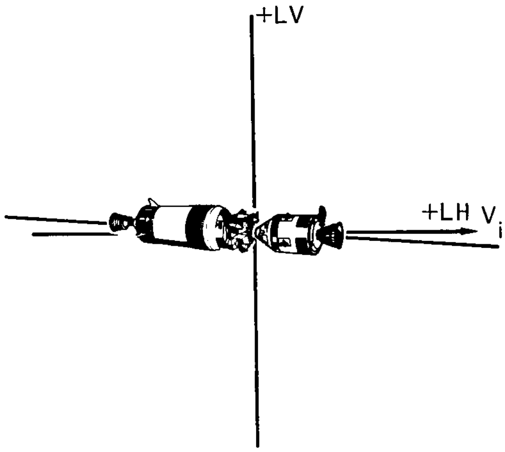


Figure 27.- Separation range of the CSM from the S-IVB versus time from separation (T and D during earth orbit).

4.2.2 CSM/LM ejection from the S-IVB during earth orbit (figs. 28 and 29).

a. CSM/LM is ejected (CSM/LM ejection can be executed at $\underline{4^h06^m00^s}$ or $\underline{5^h31^m00^s}$ g.e.t., nominal November 14, 1969, launch.
b. Coast 5 seconds.
c. Initiate CSM -X RCS translation for 3 seconds.
d. Terminate CSM -X RCS translation.
e. At 25 seconds after ejection, CSM yaws north 45° from ejection attitude.
f. CSM performs -X RCS translation for 6 seconds at 3 minutes after ejection.

CSM/LM EJECTION ATTITUDE AT 4:06:00 G.E.T.



LVLH CSM ATTITUDE

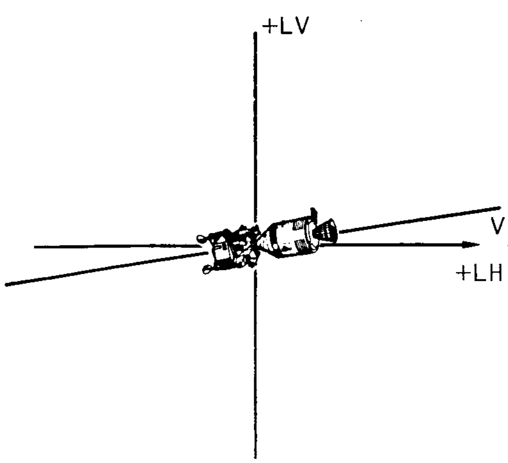
Y = 151.7
P = 003.2
R = 120.7

SPACECRAFT GIMBALS

R (OGA) = 304.0
P (IGA) = 272.0
Y (MGA) = 028.3
PAD REFSMMAT (ref. 4)

- CSM/LM EJECTION PERFORMED
- COAST 5 SEC
- CSM PERFORMS -X RCS FOR 3 SEC

CSM/LM RCS EVASIVE MANEUVER ATTITUDE AT 4:09:00 G.E.T.



LVLH CSM ATTITUDE

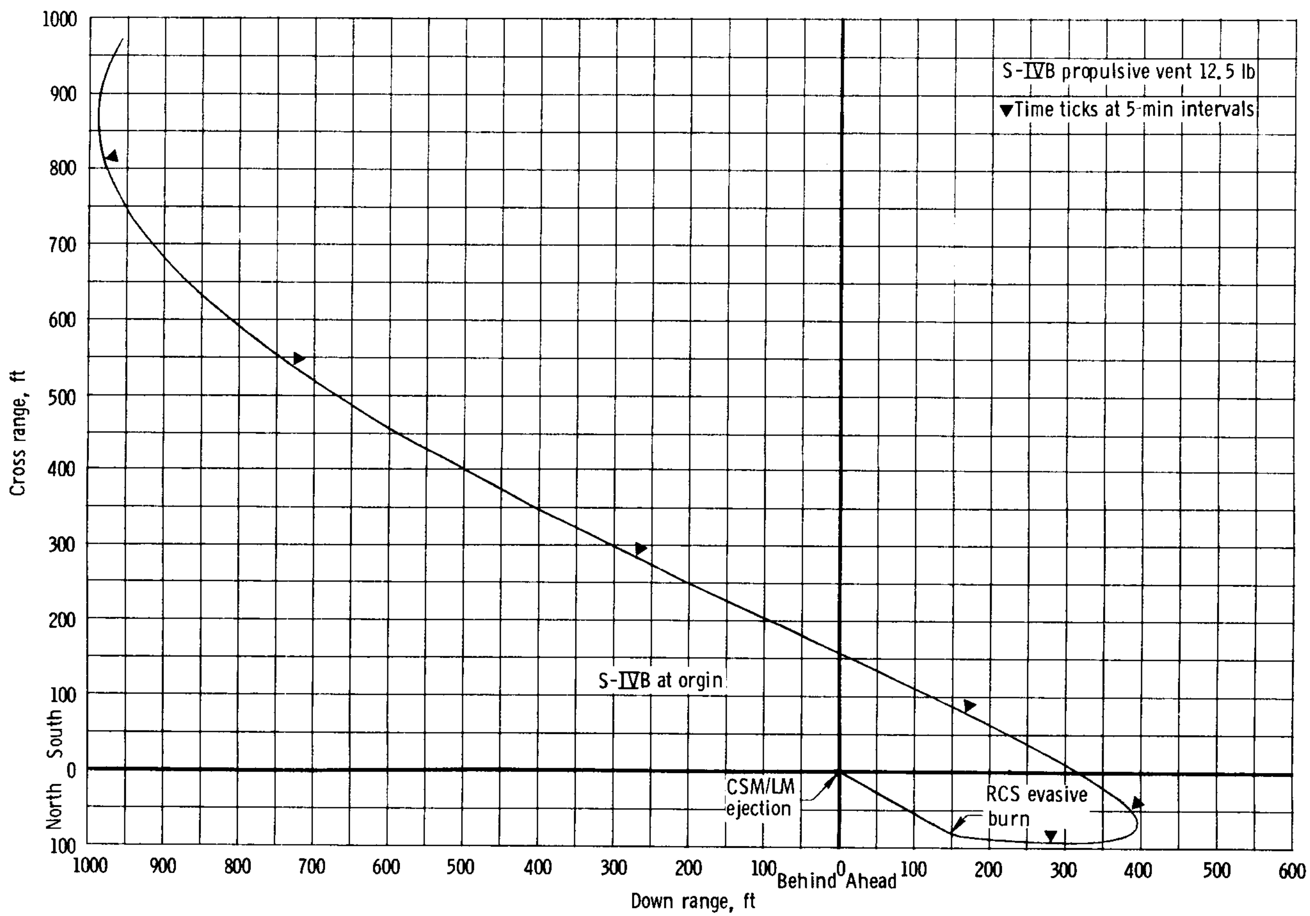
Y = -163.1
P = -008.6
R = -091.8

CSM GIMBALS FOR VIEWING S-IVB AND EVASIVE MANEUVER

R (OGA) = 092.3
P (IGA) = 273.5
Y (MGA) = 343.3

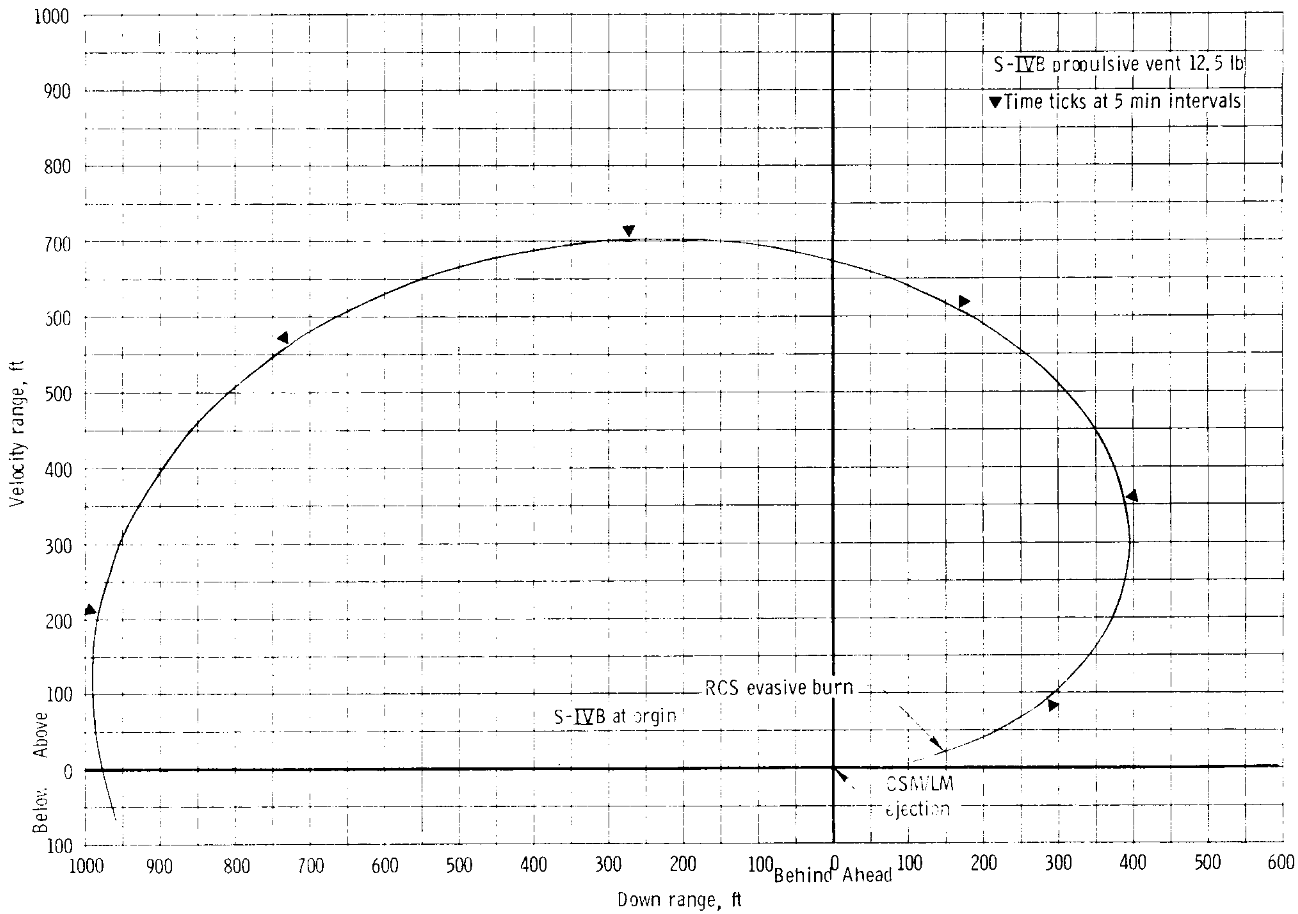
- AT 25 SEC AFTER EJECTION, CSM YAWS NORTH 45° AND ROLLS 148° FROM EJECTION ATTITUDE
- AT 3 MIN AFTER EJECTION, CSM PERFORMS -X RCS FOR 6 SEC
- ABOVE GIMBALS PERMIT CREW VISUAL MONITORING OF THE S-IVB THROUGH THE CENTER HATCH WINDOW

Figure 28.- Case: CSM/LM separation from the S-IVB; condition: alternate mission - CSM/LM ejection during earth orbit.



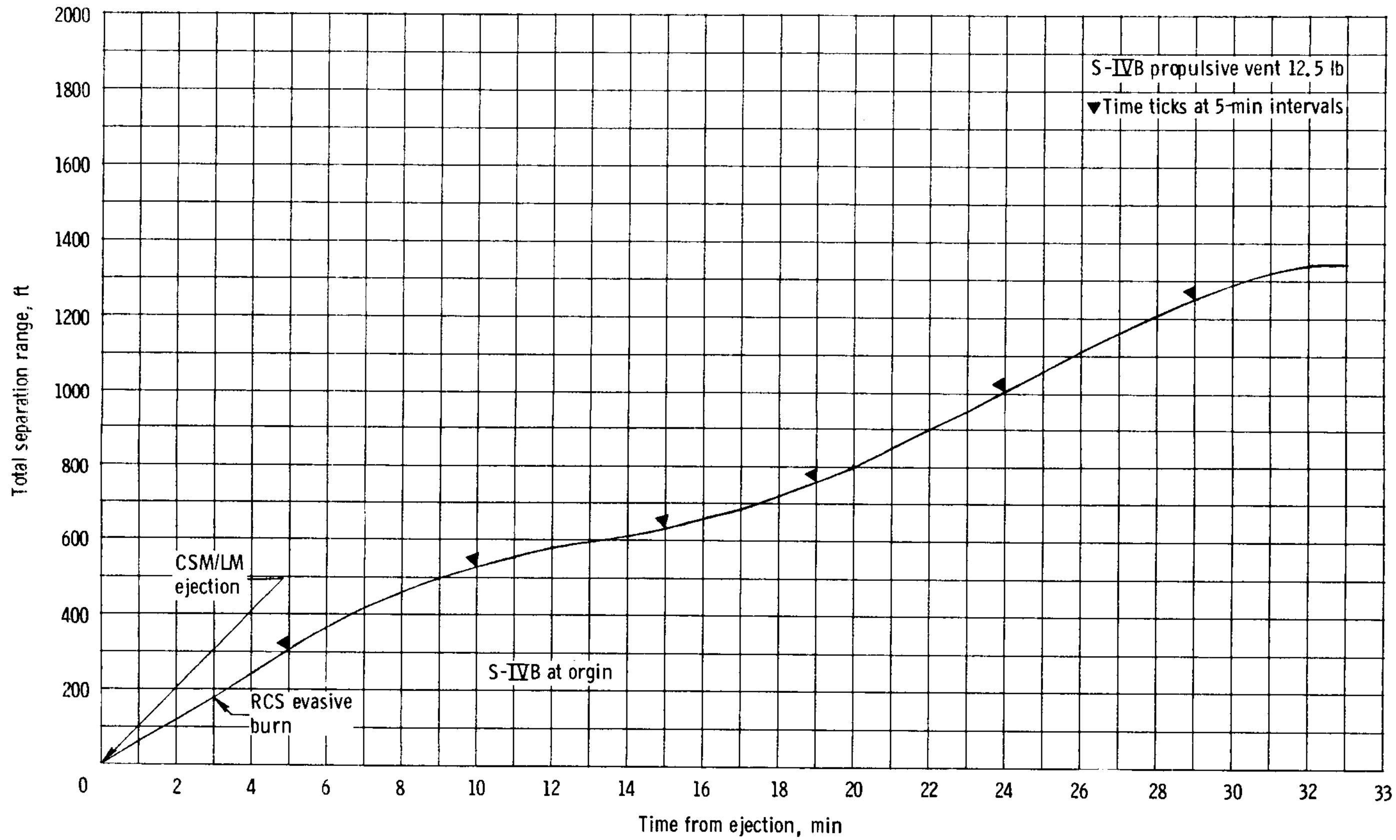
(a) Cross range versus down range.

Figure 29. - Motion of the CSM/LM relative to the S-IVB for ejection during earth orbit alternate mission.



(b) Vertical range versus down range.

Figure 29. - Continued.



(c) Total separation range versus time from ejection.

Figure 29. - Concluded.

4.2.3 LM undocking during earth orbit - same as nominal LM undocking, section 7.1.1.

4.2.4 LM staging during earth orbit[a]: no LM staging during earth orbit is planned (except for an emergency staging because of an unsafe LM descent stage)

4.2.5 LM jettison and subsequent CSM separation maneuver for deorbiting the LM during earth orbit

The following procedure is similar to that used for nominal LM jettison and deorbit during lunar orbit.

a. Orient the CSM/LM configuration to the inertial LM deorbit burn attitude. At the time of LM jettison, the CSM +X-axis will be alined with the positive radius vector, and the +Z-axis will be alined with the negative LH (heads pointed down range). The CSM LVLH attitude at ignition is yaw = $\underline{0^\circ}$, pitch = $\underline{90^\circ}$, and roll = $\underline{180^\circ}$.

b. Execute LM jettison approximately 0.75 orbit prior to LM deorbit ignition. The LM will be jettisoned radially outward (above the CSM).

c. After LM jettison, the CSM remains in the same LVLH radial attitude (yaw = $\underline{0^\circ}$, pitch = $\underline{90^\circ}$, and roll = $\underline{180^\circ}$) for the separation maneuver.

d. Execute CSM +Z RCS translation retrograde for a ΔV = $\underline{1}$ fps. The CSM separation maneuver is executed approximately $\underline{1}$ minute after LM jettison.

e. Execute the LM +X RCS deorbit burn.

The impulsive ΔV point of the burn occurs 3/4 orbit after LM jettison. Burn ΔT is approximately $\underline{5.5}$ minutes. At ignition, the LM +X-axis is pitched 169° from the positive LH. This attitude is held inertially during the burn.

No LM attitude maneuver should be required at this time because the LM was jettisoned in the inertial deorbit burn attitude.

[a]Deorbiting the entire LM will take priority over staging during earth orbit alternate missions except for an unsafe LM descent stage. For emergency docked or undocked staging procedures, see section 4.1.7.

f. At the time of LM deorbit ignition, the CSM will be located 13 150 feet ahead and 1300 feet below the LM. The LM will pass below the CSM at a range of approximately 6.3 n. mi. and will continue to increase in range below and behind the CSM until impact occurs.

6.0 TLC PHASE

6.1 Nominal mission separation procedures

6.1.1 CSM separation from the S-IVB, transposition and docking (figs. 30 and 31)

Ground elapsed time,[a] hr:min:sec	Time from TLI cutoff,[b] hr:min:sec	Event
2:52:43.7	00:00:00	S-IVB holds TLI cutoff attitude.
2:53:03.7	00:00:20	S-IVB orients to and holds local horizontal (LH).
3:07:43.7	00:15:00	S-IVB orients to and holds T, D, and E attitude of yaw -30°, pitch 120°, roll 180° with respect to the LH (November 14 launch).
3:17:43.7	00:25:00	CSM separates from the S-IVB, and SLA panels are jettisoned. ΔV imparted to S-IVB at SEP is approximately 0.2 fps. Perform CSM +X RCS translation for a ΔV = 0.8 fps.
3:18:18.7	00:25:35	Perform CSM -X RCS to null 0.3-fps separation rate.
3:18:23.7	00:25:40	Initiate CSM pitch of 180° at 1.5-deg/sec rate.
3:20:23.7	00:27:40	Null CSM pitch rate. Initiate CSM roll left 60° at 0.5-deg/sec rate.
3:22:23.7	00:29:40	Null CSM roll rate. Perform CSM +X RCS to null 0.5-fps separation rate. Initiate 1.0-fps closing rate.

[a]For a nominal November 14, 1969, launch (ref. 5).

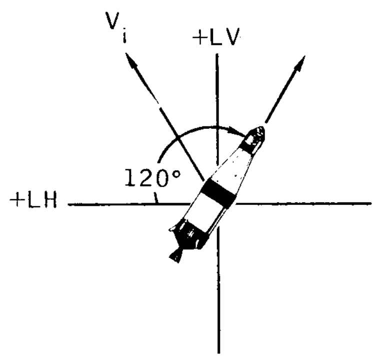
[b]TLI cutoff for November 14, 1969, nominal launch is approximately $2^h52^m43.7^s$ g.e.t. based on a TLI ΔT = 322.0 seconds (ref. 5).

Ground elapsed time,[a] hr:min:sec	Time from TLI cutoff,[b] hr:min:sec	Event
3:27:13.7	00:34:30	Perform CSM -X RCS to null 1.0-fps closing rate.
3:27:18.7	00:34:35	Begin docking. Estimated worst case dock is completed by TLI cutoff plus $1^h 20^m$. The nominal T&D procedure is taken from reference 5.

[a]For a nominal November 14, 1969, launch (ref. 5).

[b]TLI cutoff for November 14, 1969, nominal launch is approximately $2^h 52^m 43.7^s$ g.e.t. based on a TLI ΔT = 322.0 seconds (ref. 5).

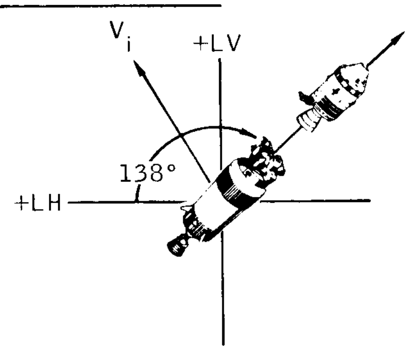
LAUNCH VEHICLE ORIENTS TO THIS ATTITUDE AT TLI C/O + 15 MIN



LVLH CSM ATTITUDE

P = 120	Y = -130.9
Y = -030	P = 048.6
R = 000	R = -139.1

SEPARATION ATTITUDE FOR T AND D AT TLI C/O + 25 MIN



LVLH CSM ATTITUDE

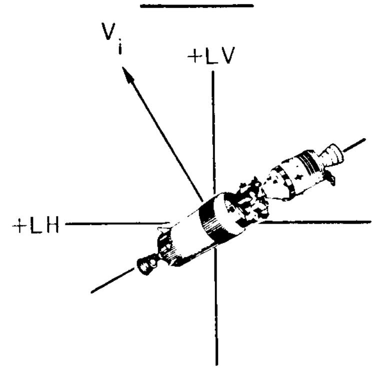
P = 138	Y = -142.1
Y = -030	P = 035.5
R = 000	R = -155.7

CSM GIMBALS

R (OGA) = 356.0
P (IGA) = 092.0
Y (MGA) = 331.7
PAD REFSMMAT (ref. 4)

- CSM PERFORMS +X RCS FOR ΔV = 0.8 FPS
- ΔV IMPARTED TO LAUNCH VEHICLE AT SEP IS APPROXIMATELY 0.2 FPS

DOCKING



SPACECRAFT GIMBALS

R (OGA) = 304.0
P (IGA) = 272.0
Y (MGA) = 028.3
PAD REFSMMAT (ref. 4)

- CSM NULLS 0.3 FPS WITH -X RCS AT 35 SEC AFTER SEPARATION
- CSM PITCHES 180° AT 2 DEG/SEC RATE
- CSM NULLS 0.5 FPS AND PERFORMS 1.0 FPS CLOSING RATE WITH +X RCS
- CSM BEGINS DOCKING APPROXIMATELY 10 MIN AFTER SEPARATION

Figure 30.- Case: CSM separation from the S-IVB/LM; condition: nominal T and D.

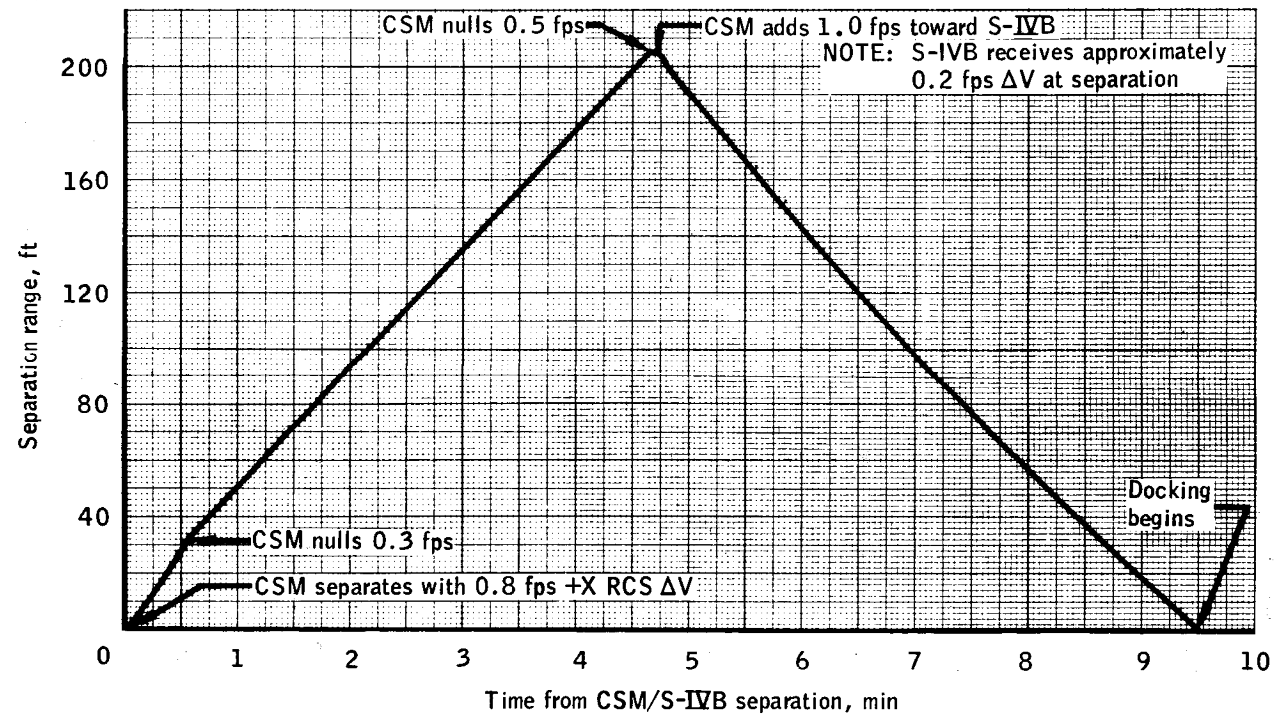


Figure 31.- Separation range of the CSM from the S-IVB versus time from separation (nominal T and D).

6.1.2 LM ejection and S-IVB APS evasive maneuver or CSM backup evasive maneuver (figs. 32, 33, and 34)

Ground elapsed time,[a] hr:min:sec	Time, hr:min:sec	Event
4:12:43.7	00:00:00	CSM/LM ejection from the S-IVB (TLI cutoff plus 1^h20^m or $4^h12^m43.7^s$ g.e.t.) for November 14, 1969, nominal launch (ref. 5). Spring actuator ΔV is approximately 0.8 fps for a 48 percent efficiency.
4:12:48.7	00:00:05	Initiate CSM RCS -X translation. No change in spacecraft attitude.
4:12:51.7	00:00:08	Terminate CSM RCS -X translation. ΔV = 0.4 fps. Total ejection ΔV = 1.2 fps.
4:13:05.2	00:00:21.5	The spacecraft will have translated approximately 25 feet based on a minimum spring efficiency of 48 percent. After ejection, begin orientation to acquire the S-IVB in the hatch window field of view. Spacecraft gimbal angles to view the S-IVB for a nominal November 14, 1969 launch are pitch (IGA) = 277.1°, yaw (MGA) = 343.5°, and roll (OGA) = 96.3°. These values correspond to a CSM LVLH yaw maneuver of -45° and a roll maneuver of 153.6°.
4:15:43.7	00:03:00	The crew should confirm that the S-IVB was acquired in the hatch window field of view.
4:16:13.7	00:03:30	The ground command is sent for the S-IVB orient at a 0.3 deg/sec rate to the APS evasive maneuver attitude. The APS evasive maneuver attitude is the inertial T, D, and E attitude with an opposite sign yaw gimbal angle. The S-IVB APS evasive

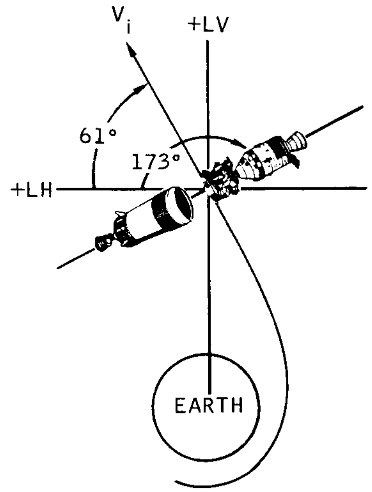
[a]For a nominal November 14, 1969, launch.

Ground elapsed time,[a] hr:min:sec	Time, hr:min:sec	Event
		maneuver inertial attitude is pitch (IGA) = 2.0°, yaw (MGA) = 28.3°, and roll (OGA) = 176°. At the time of APS ignition, this corresponds to an S-IVB LVLH attitude of pitch = 170.5°, yaw = 26.5°, and roll = 180°. The earliest possible time that this ground command can be sent is TB7 + 3600 seconds. Approximately 8 minutes are allowed for the S-IVB to maneuver to and maintain the evasive attitude. The crew should confirm that the S-IVB is in and holding the evasive attitude prior to TB8 inhibit release.
4:24:23.7	00:11:40 (TB8 + 0.0 sec)	TB8 inhibit release is commanded. S-IVB APS evasive maneuver is initiated. If the S-IVB APS evasive maneuver fails, the CSM will perform a 5- to 10-second +X RCS backup evasive maneuver in the S-IVB viewing attitude. Relative motion for this contingency is presented in figure 34.
4:25:44.9	00:13:01.2 (TB8 + 81.2 sec)	Terminate S-IVB APS evasive maneuver. ΔV = 10 fps.
4:34:03.7	00:21:20 (TB8 + 580 sec)	The S-IVB initiates the maneuver to and maintains the slingshot attitude. The local horizontal slingshot attitude for a November 14, 1969, launch is pitch = 191°, yaw = 0°, and roll = 180°.
4:34:03.9	00:21:20.2 (TB8 + 580.2 sec)	Continuous H_2 vent is ON.
4:45:43.7	00:33:00 (TB8 + 1280 sec)	Begin S-IVB LOX dump.

[a]For a nominal November 14, 1969, launch.

Ground elapsed time,[a] hr:min:sec	Time, hr:min:sec	Event
4:46:41.7	00:33:58 (TB8 + 1338 sec)	End LOX dump. Total ΔV for LOX dump and H_2 vent is approximately 49.2 fps or 15.0 m/sec.
5:21:03.7	01:08:20 (TB8 + 3400 sec)	APS ullage ignition occurs.
5:26:18.7	01:13:35 (TB8 + 3715 sec)	Terminate APS ullage maneuver. APS and H_2 vent ΔV is approximately 55.8 fps or 16.0 m/sec. Total S-IVB slingshot ΔV for November 14 launch is approximately 115 fps.

CSM/LM EJECTION ATTITUDE AT TLI C/O + $1^h 20^m$



LVLH CSM ATTITUDE

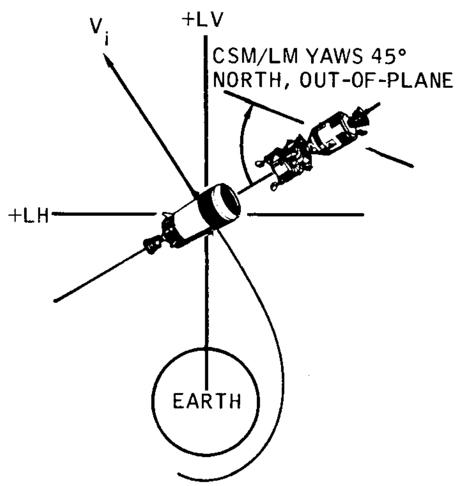
P = -008.7	Y = 030.3
Y = 030.0	P = -007.6
R = -060.0	R = -064.4

- EXECUTE CSM/LM EJECTION
- AT 5 SECONDS AFTER EJECTION PERFORM CSM -X RCS FOR 3 SEC
- TOTAL $\Delta V \cong$ 1.2 FPS FOR 48% EFFICIENT SPRING EJECTION

CSM GIMBALS

R (OGA) = 304.0
P (IGA) = 272.0
Y (MGA) = 028.3
PAD REFS (ref. 4)

CSM/LM ATTITUDE FOR VIEWING S-IVB THROUGH HATCH WINDOW



CSM GIMBALS FOR VIEWING S-IVB THROUGH HATCH WINDOW

R (OGA) = 96.3
P (IGA) = 277.1
Y (MGA) = 343.5
PAD REFS

CORRESPONDING LVLH ATTITUDE AT APS IGNITION

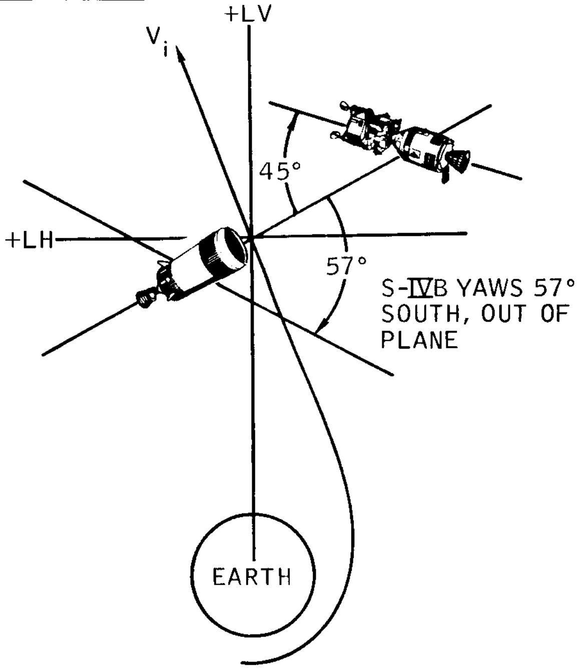
P = -003.6	Y = -015.0
Y = -015.0	P = -003.5
R = 092.6	R = 093.5

- AFTER CSM/LM EJECTION, ORIENT TO THE S-IVB VIEWING ATTITUDE

Figure 32.- Case: CSM/LM separation from the S-IVB; condition: nominal CSM/LM ejection and S-IVB APS evasive maneuver.

S-IVB APS EVASIVE MANEUVER ATTITUDE AT TLI

C/0 + $1^h 31^m 40^s$



S-IVB EVASIVE MANEUVER GIMBALS

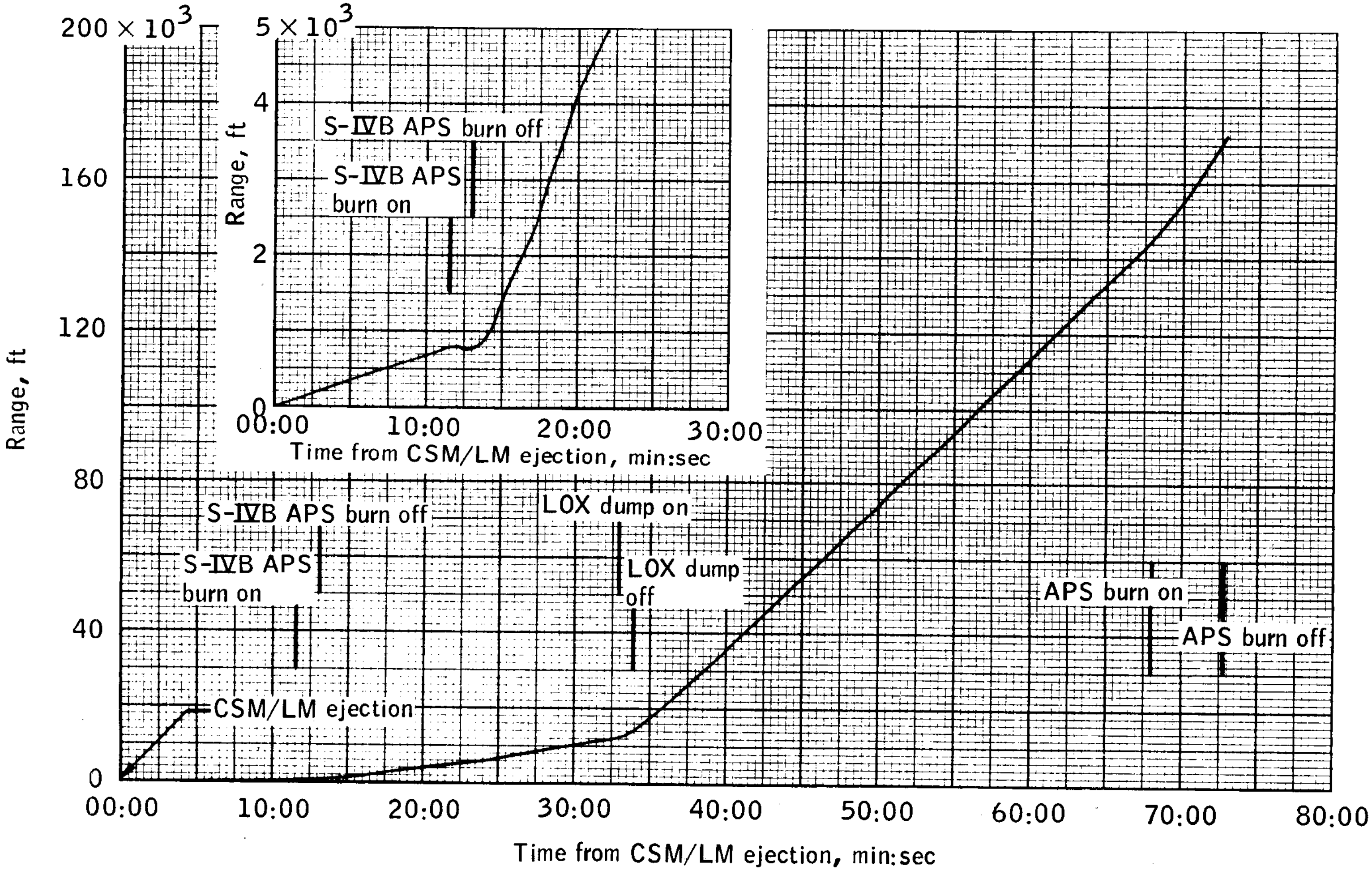
R (OGA) = 176.0
P (IGA) = 002.0
Y (MGA) = 028.3

CORRESPONDING S-IVB LVLH ATTITUDE AT APS IGNITION

P = 170.5	Y = 153.2
Y = 26.5	P = 008.5
R = 180.0	R = -004.4

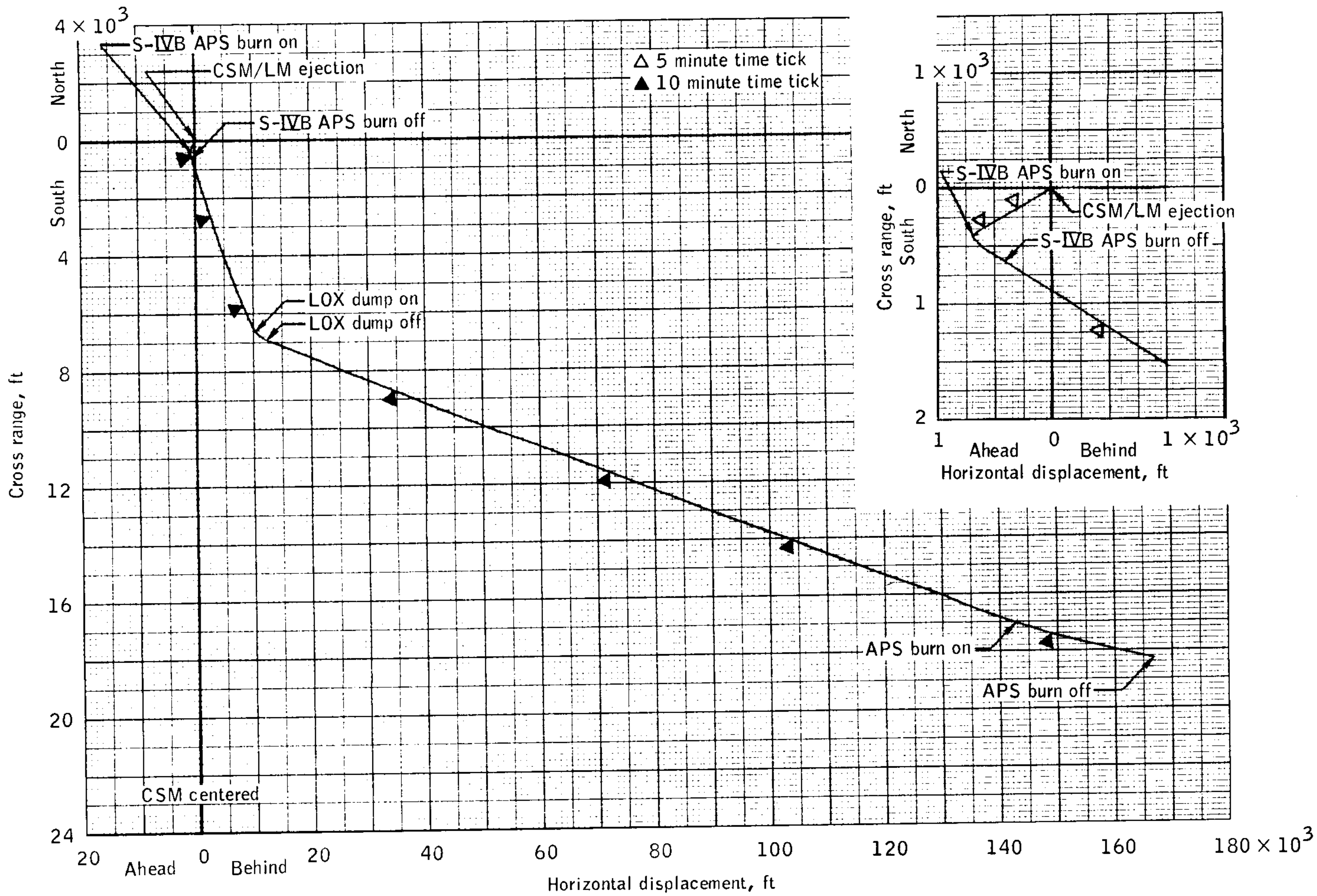
- UPON GROUND COMMAND, S-IVB ORIENTS TO APS EVASIVE ATTITUDE
- AFTER APPROXIMATELY 8 MIN THE TB8 INHIBIT RELEASE WILL BE SENT AND APS IGNITION WILL OCCUR
- THE S-IVB APS BURNS FOR 81.2 SEC, ΔV = 10.0 FPS
- THE S-IVB LOX DUMP BEGINS AT TB8 + $21^m 20^s$ AND LASTS 58 SEC. TOTAL ΔV FOR THE DUMP AND H_2 VENTING IS APPROXIMATELY 49.2 FPS
- THE S-IVB SLINGSHOT LOCAL HORIZONTAL ATTITUDE FOR NOVEMBER 14, 1969, IS PITCH = 191°, YAW = 0° AND ROLL = 180°
- THE SECOND S-IVB APS BURN BEGINS AT TB8 + $56^m 40^s$ AND YIELDS A ΔV OF 55.8 FPS. TOTAL S-IVB SLINGSHOT ΔV INCLUDING VENTING IS APPROXIMATELY 115 FPS

Figure 32.- Concluded.



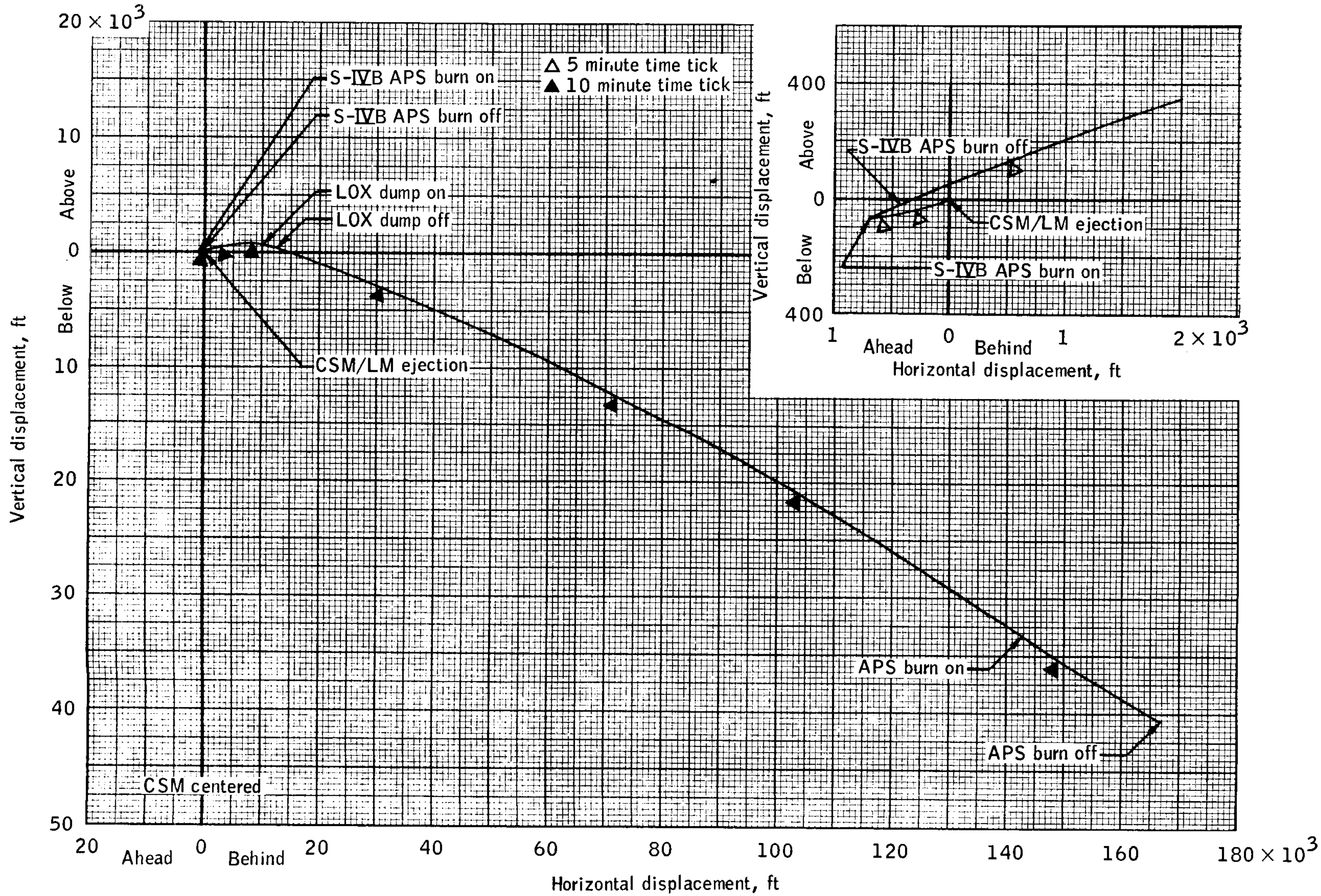
(a) Range versus time.

Figure 33.- Motion of the S-IVB relative to the spacecraft for the S-IVB evasive maneuver on Apollo Mission H-1.



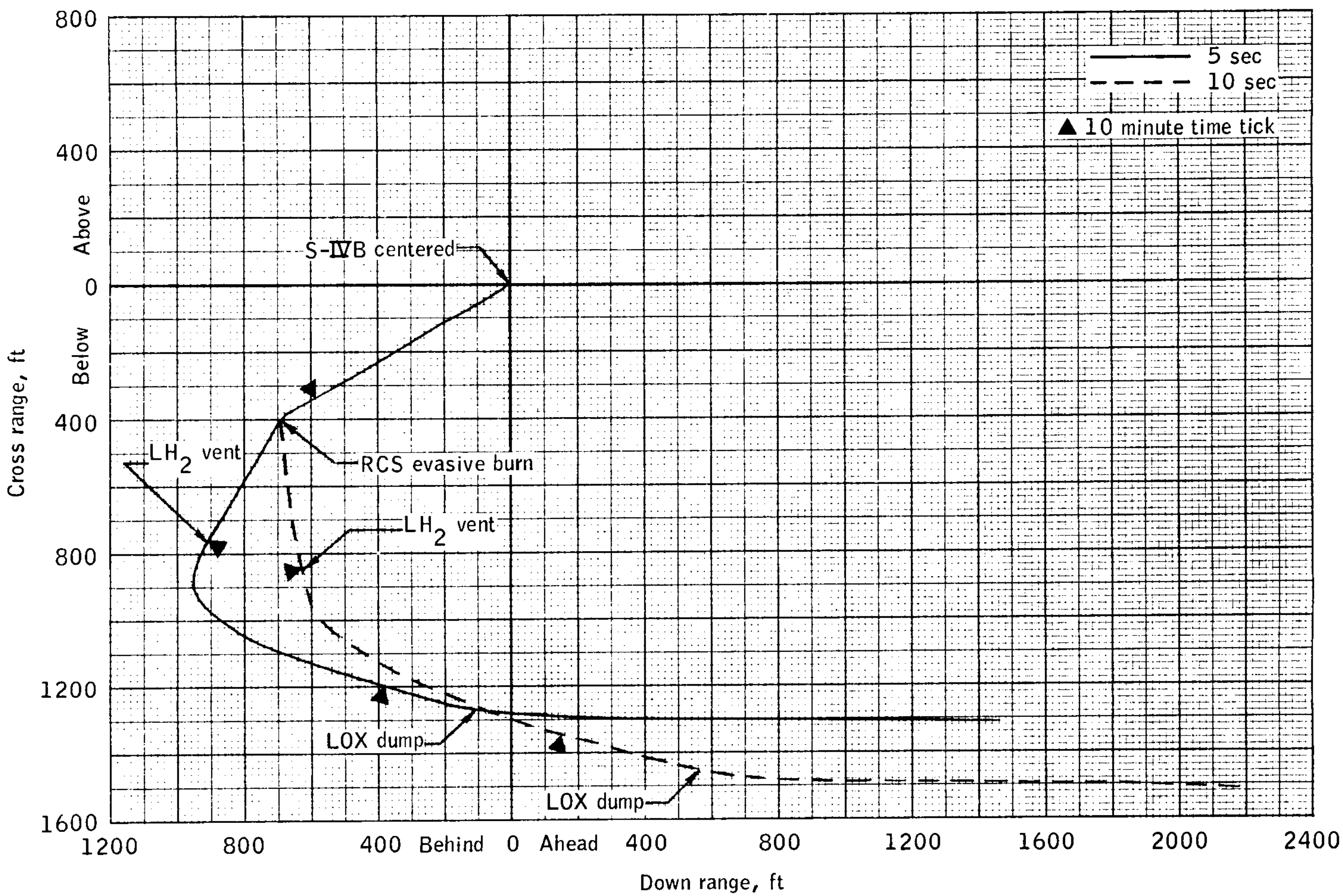
(b) Cross range versus horizontal displacement.

Figure 33.- Continued.



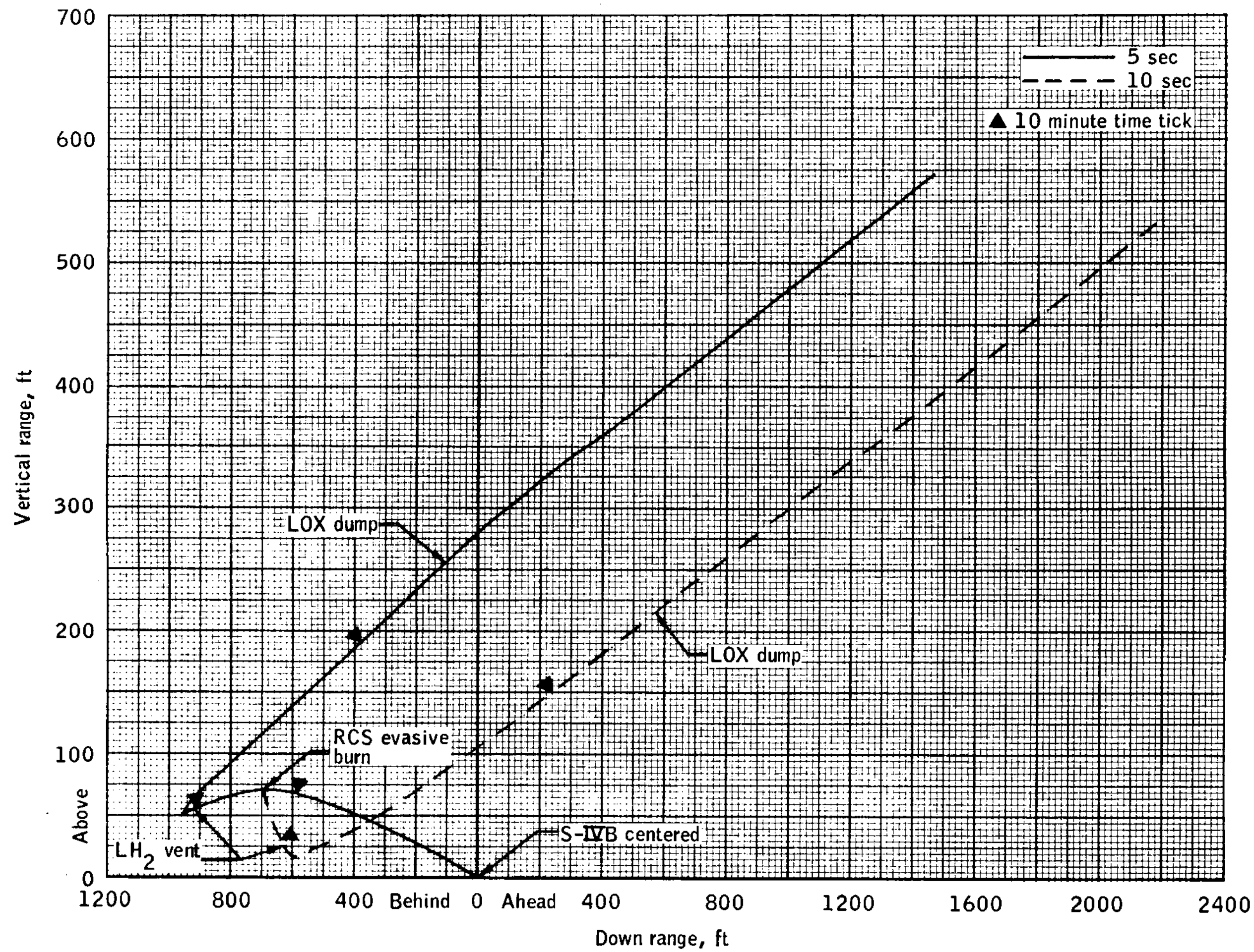
(c) Vertical displacement versus horizontal displacement.

Figure 33.- Concluded.



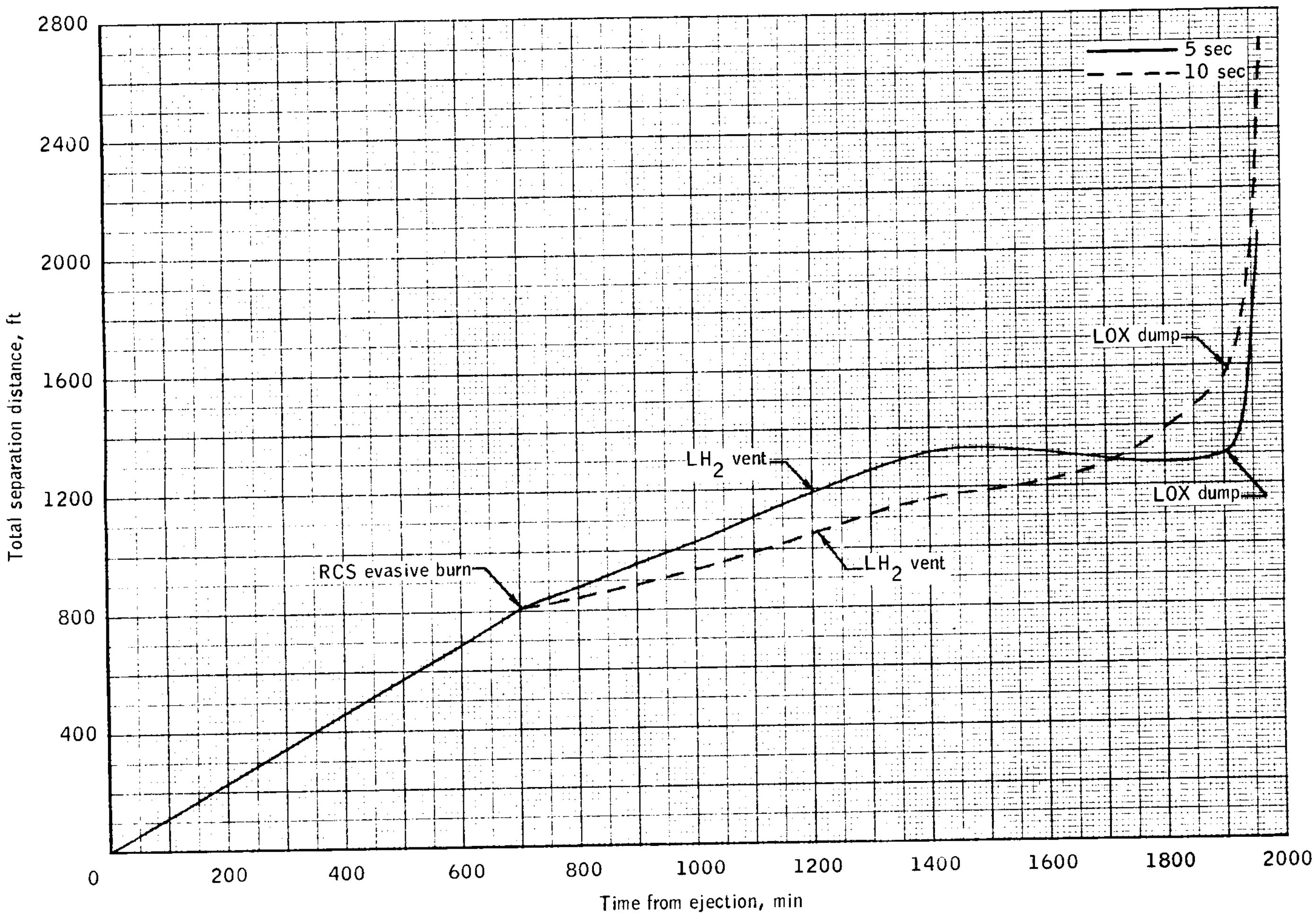
(a) Cross range versus down range.

Figure 34.- Motion of the CSM/LM relative to the S-IVB following ejection for the RCS alternate evasive maneuver.



(b) Vertical range versus down range.

Figure 34.- Continued.



(c) Total separation distance versus time from ejection.

Figure 34.- Concluded.

6.1.3 Emergency separation procedure for an impending S-IVB explosion (for more detailed data, see ref. 6) (figs. 35 and 36)

6.1.3.1 In earth orbit through nominal CSM/S-IVB separation - presented in section 4.1.5

6.1.3.2 CSM/S-IVB separation until orientation is begun to view the S-IVB

Time after warning is received, min:sec	Event
00:00	Warning received; no CSM orientation required
00:06	SPS ON as soon as possible
00:11	SPS OFF; burn Δt = 5 seconds, ΔV = 50 fps
02:20	Safe distance achieved for a CSM weight of 64 000 pounds
03:20	S-IVB destruction occurs

6.1.3.3 Begin orientation to view the S-IVB until translation toward the S-IVB is begun

Time after warning is received, min:sec	Event
00:00	Warning received
00:06	Begin orientation to SPS burn attitude as soon as possible; burn attitude: R(OGA) = crew option, P(IGA) = 193.9°, Y(MGA) = 60.4°
01:05	End orientation as soon as possible; SPS ON
01:10	SPS OFF; burn Δt = 5 seconds, ΔV = 50 fps
03:16	Safe distance achieved for a CSM weight of 64 000 pounds
03:20	S-IVB destruction occurs

6.1.3.4 Begin translation toward S-IVB until umbilical hookup[a]

Time after warning is received, min:sec	Event
00:00	Warning received; undock if necessary; CSM -X RCS ON
00:06	-X RCS OFF; orient to SPS burn attitude: R(OGA) = crew option; P(IGA) = 193.9°, Y(MGA) = 60.4°
01:05	End orientation as soon as possible; SPS ON
01:10	SPS OFF; burn Δt = 5 seconds, ΔV = 50 fps
03:16	Safe distance achieved for a CSM weight of 64 000 pounds
03:20	S-IVB destruction occurs

6.1.3.5 Umbilical hookup until CSM/LM ejection plus 8 seconds

Time after warning is received, min:sec	Event
00:00	Warning received; perform nominal CSM/LM ejection
00:05	CSM -X RCS ON
00:08	CSM -X RCS OFF
00:22	Orient to SPS burn attitude: R(OGA) = crew option, P(IGA) = 193.9°, Y(MGA) = 60.4°
01:05	End orientation as soon as possible; SPS ON
01:14	SPS OFF; burn Δt = 9 seconds, ΔV = 60 fps
03:05	Safe distance achieved for a CSM/LM weight of 96 000 pounds
03:20	S-IVB destruction occurs

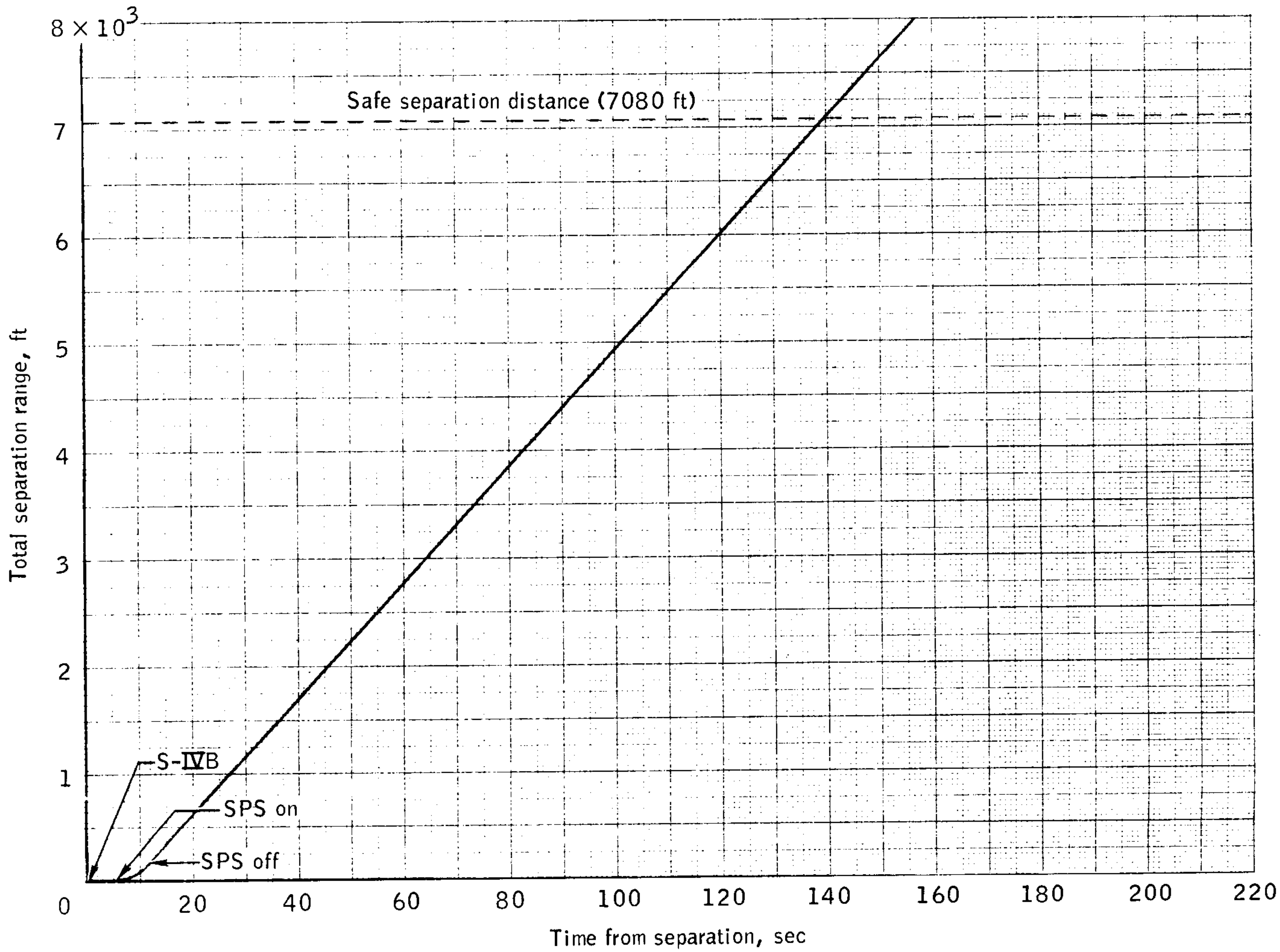
[a]The crew could be performing umbilical hookup operations at the time the warning is received; therefore, separation could not be performed at warning. In this case, the crew would have to separate as soon as possible, orient to the burn attitude, and burn the SPS as long as necessary.

6.1.3.6 CSM/LM ejection plus 8 seconds through ejection plus 3 minutes

Time after warning is received, min:sec	Event
00:00	Warning received
00:22	Orient to SPS burn attitude: R(OGA) = crew option, P(IGA) = 193.9°, Y(MGA) = 60.4°
01:05	End orientation as soon as possible; SPS ON
01:14	SPS OFF; burn Δt = 9 seconds, ΔV = 60 fps
03:05	Safe distance achieved for a CSM/LM weight of 96 600 pounds
03:20	S-IVB destruction occurs

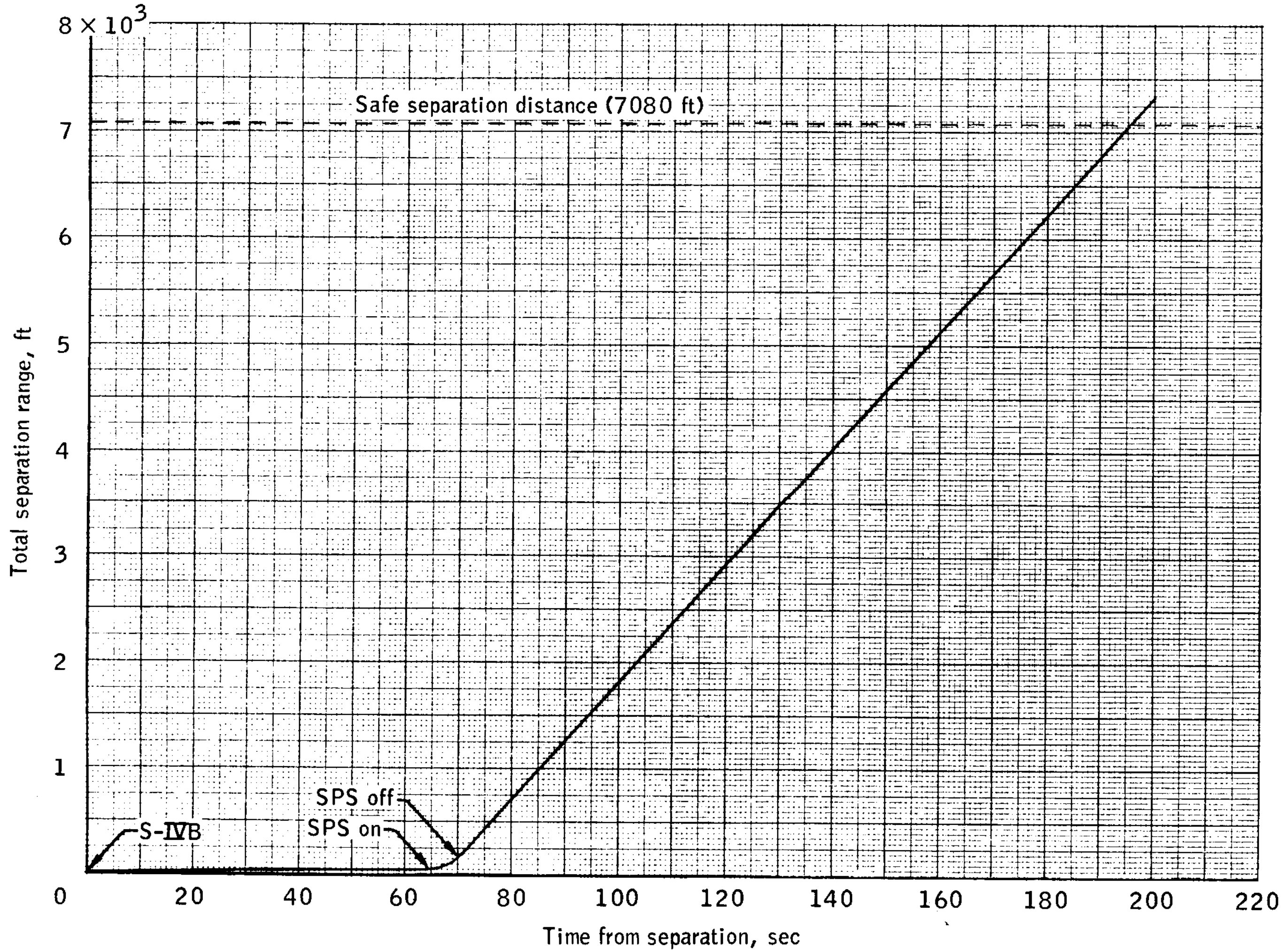
6.1.3.7 CSM/LM ejection plus 3 minutes until safe separation is nominally achieved

Time after warning is received, min:sec	Event
00:00	Warning received; no CSM/LM orientation is required
00:06	SPS ON as soon as possible
00:12	SPS OFF; burn Δt = 6 seconds, ΔV = 40 fps
03:12	Safe distance achieved for a CSM/LM weight of 96 600 pounds
03:20	S-IVB destruction occurs



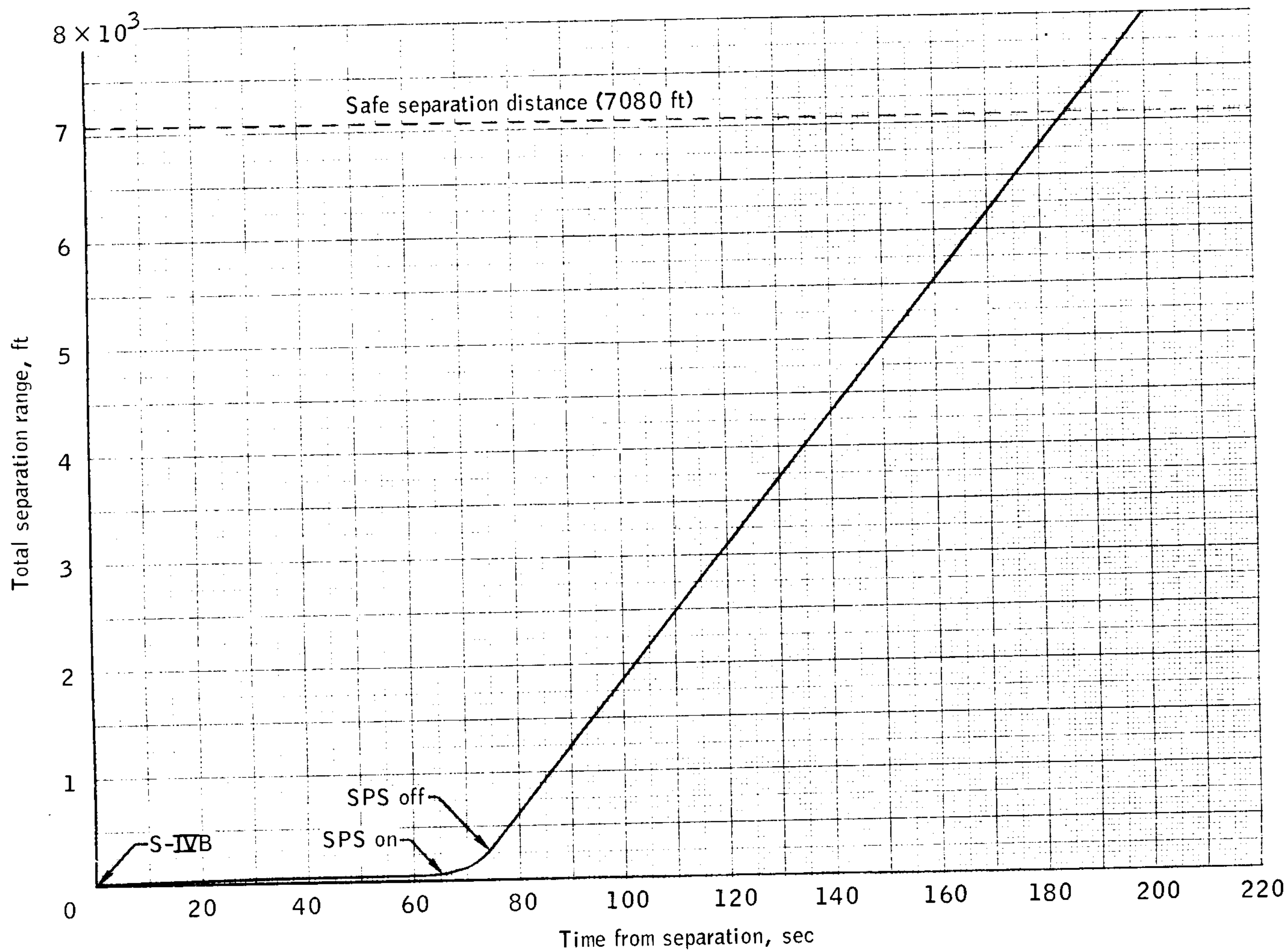
(a) Earth parking orbit alternates and nominal CSM/S-IVB separation through begin orientation to view the S-IVB.

Figure 35.- Total separation range between the CSM and booster as a function of time from separation for an impending S-IVB explosion (Apollo 12).



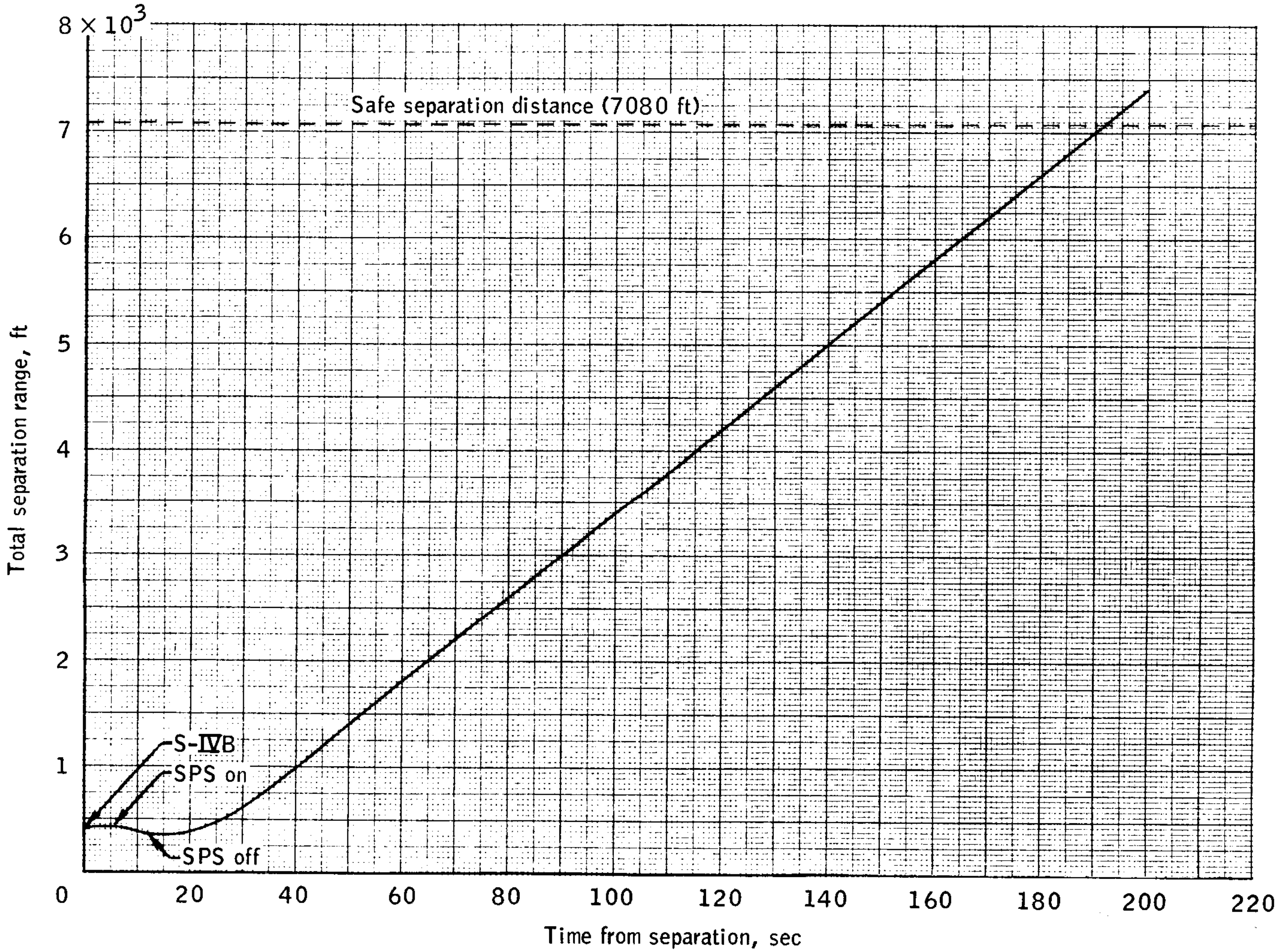
(b) Begin orientation to view the S-IVB through umbilical hookup.

Figure 35.- Concluded.



(a) Umbilical hookup until ejection plus 3 minutes.

Figure 36.- Total separation range between the CSM plus LM and booster as a function of time from separation for an impending S-IVB explosion (Apollo 12).



(b) Ejection plus 3 minutes until a safe separation distance is nominally obtained.

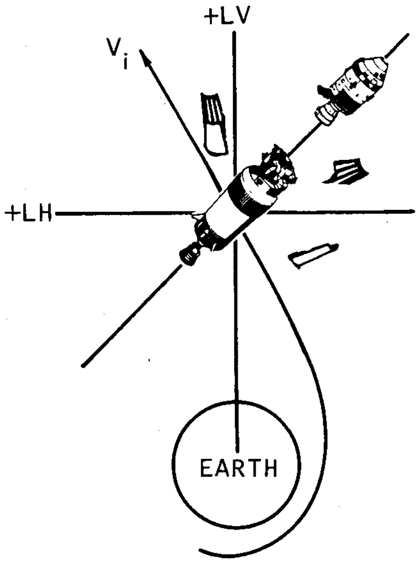
Figure 36.- Concluded.

6.2 Aborts during TLC

6.2.1 TLI 90-minute abort (figs. 37 and 38)

Time from TLI plus 25 min min:sec	Event
00:00	Initiate abort (decision to abort made prior to time of CSM/S-IVB separation at TLI cutoff plus 25 minutes), +X RCS four-jet direct ullage ON
00:03	CSM/S-IVB physical separation (S-IVB propulsive vent is not on).
00:05	Direct ullage becomes +X RCS jet translation.
00:14	Terminate +X RCS jet translation; crew pitch up to local vertical (CSM +X-axis toward the earth).
01:00	-X RCS jet translation for ΔV of 1.5 fps.
01:08	Terminate -X RCS jet translation; maneuver to the abort burn attitude
60:00	SPS ignition occurs.

CSM ATTITUDE AT SEPARATION



CSM GIMBALS

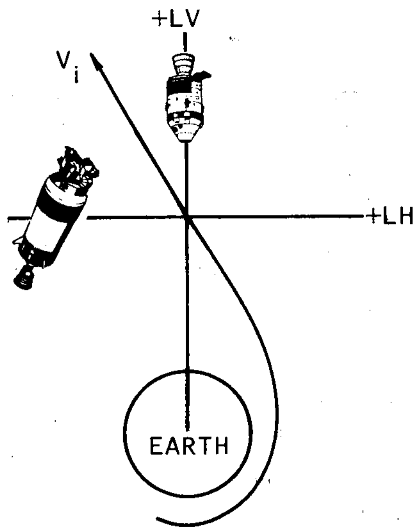
R (OGA) = 356.0
P (IGA) = 092.0
Y (MGA) = 331.7
PAD REFSMMAT (ref. 4)

LVLH CSM ATTITUDE

P = 138.0	Y = -142.1
Y = -030.0	P = 035.5
R = 000.0	R = -155.7

- DECISION TO ABORT MADE PRIOR TO TIME OF NOMINAL CSM/S-IVB SEPARATION (TLI C/O $+25^m$)
- CSM SEPARATES WITH +X RCS FOR 14 SEC
- CSM PHYSICAL SEPARATION OCCURS AT 3 SEC
- CSM ORIENTS +X WITH LOCAL VERTICAL, APEX TOWARDS EARTH

CSM ATTITUDE FOR 1.5-FPS RCS MANEUVER

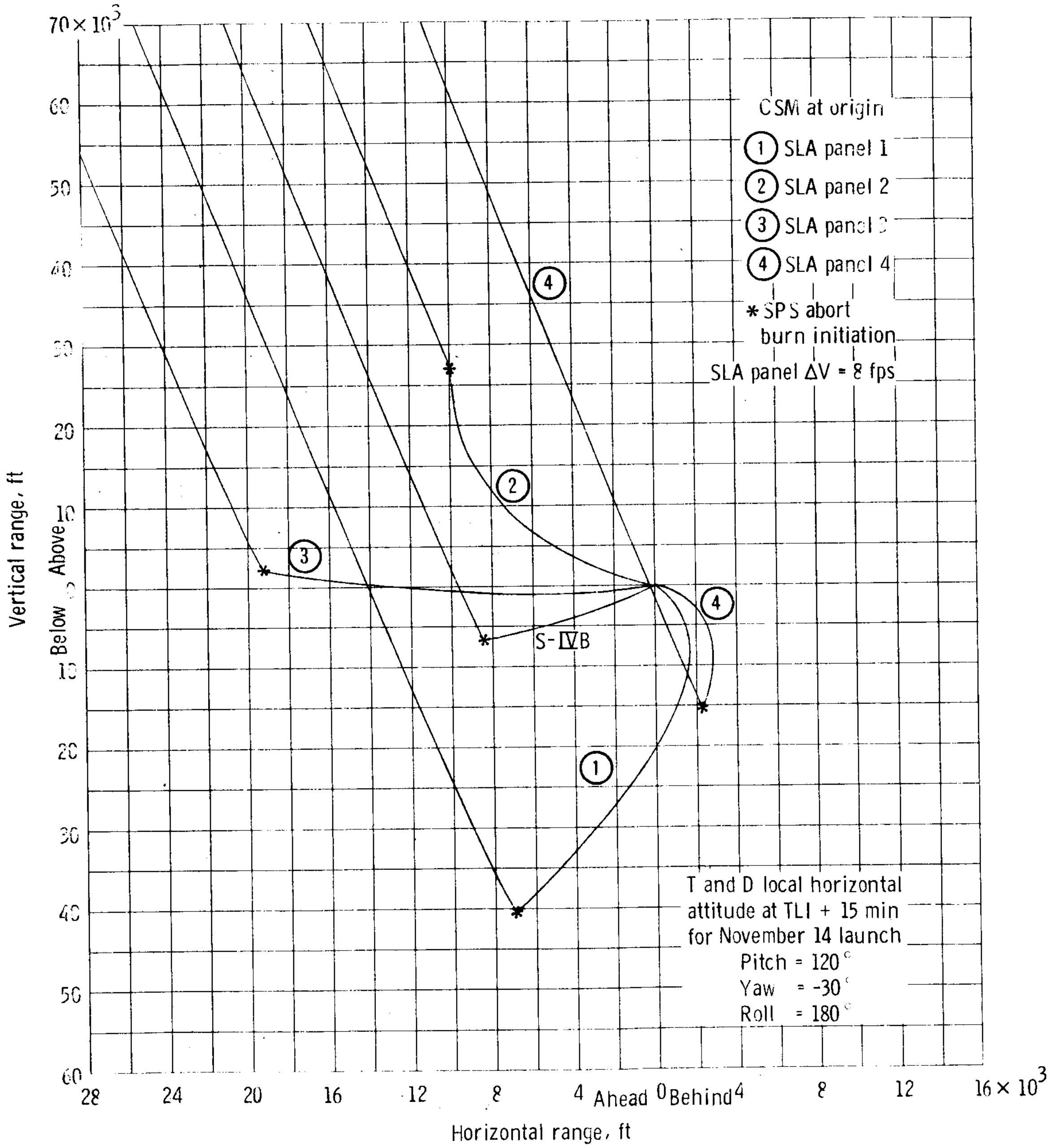


LVLH CSM ATTITUDE

P = -090	Y = 000
Y = 000	P = -090
R = 000	R = 000

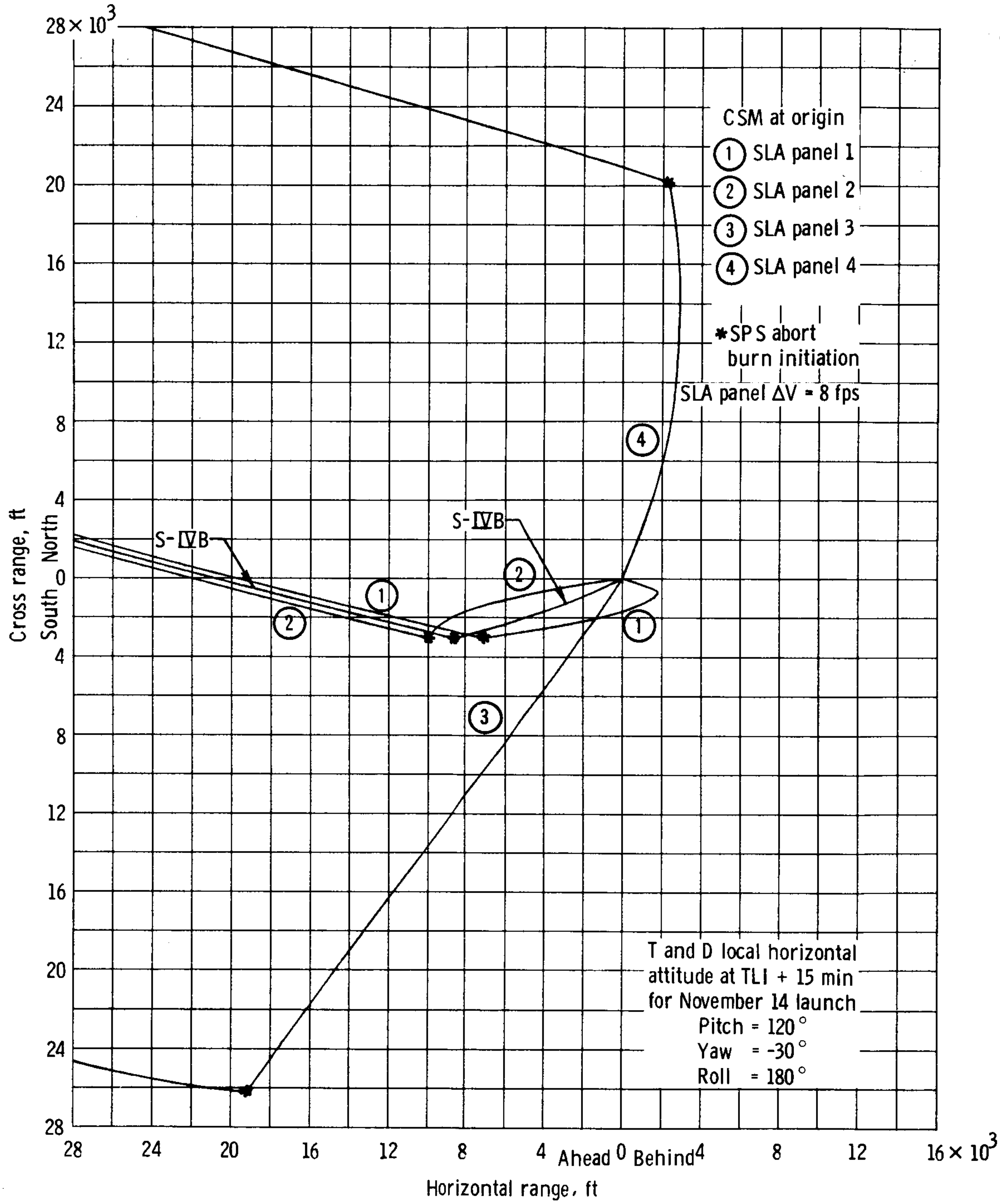
- CSM PERFORMS -X RCS FOR ΔV OF 1.5 FPS AT 1 MIN AFTER SEPARATION
- CSM ORIENTS TO SPS ABORT BURN ATTITUDE

Figure 37.- Case: CSM separation from the SLA/LM/S-IVB; condition: TLI 90-minute abort.



(a) Vertical range versus horizontal range.

Figure 38. - Radially outward evasive maneuver for TLI 90-minute abort: relative motion of the S-IVB and SLA panels with respect to the CSM (panel jettison attitude, θ, 90°).



(b) Cross range versus horizontal range.

Figure 38. - Concluded.

6.2.2 Direct abort from TLC (figs. 39 and 40)

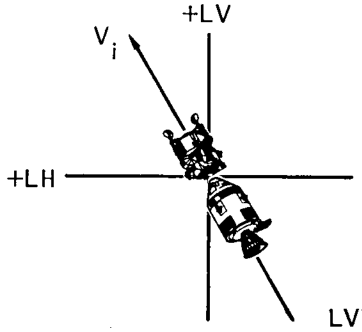
a. Aline the CSM +X-axis 180° from the SPS abort burn attitude (near the radius vector).

b. Execute LM jettison and perform CSM -X RCS translation for a net separation velocity of 1.0 fps.

c. Coast for 30 minutes; orient to the ground computed abort attitude.

d. Perform the SPS abort maneuver.

LM JETTISON ATTITUDE



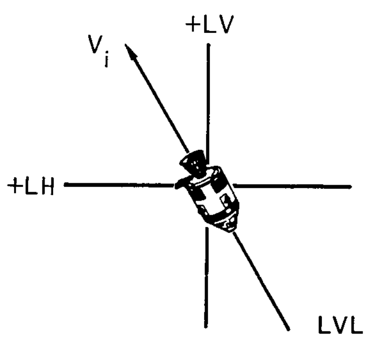
LVLH EARTH REFERENCED

LVLH CSM ATTITUDE

P = ~090	Y = 000
Y = 000	P = ~090
R = 000/180	R = 000/180

- CSM JETTISONS LM
- CSM PERFORMS RCS -X RETROGRADE FOR NET $\Delta V = 1.0$ FPS

CSM SPS ABORT BURN ATTITUDE



LVLH EARTH REFERENCED

LVLH CSM ATTITUDE

P = ~-090	Y = 000
Y = 000	P = ~-090
R = 000/180	R = 000/180

- CSM COASTS 30 MIN AND THEN ORIENTS TO THE GROUND COMPUTED ABORT ATTITUDE

Figure 39.- Case: CSM separation from LM; condition: LM jettison for direct abort from TLC.

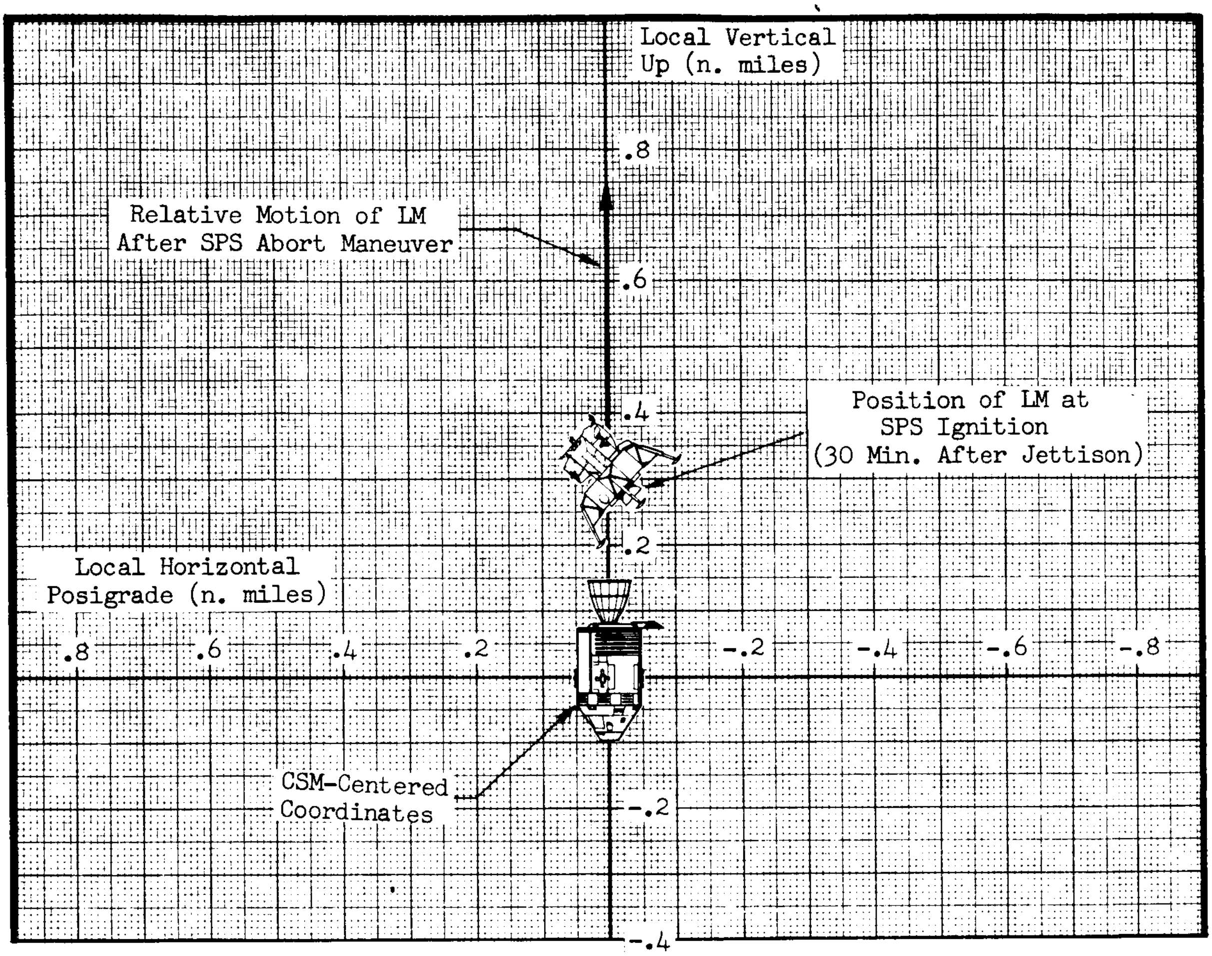


Figure 40.- Relative motion for LM jettison prior to direct abort from TLC.

6.2.3 Circumlunar aborts

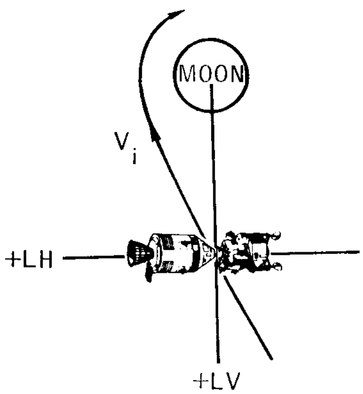
6.2.3.1 LM jettison during TLC[a] (same procedure as LM staging during TLC, section 6.3.2) (figs. 41 and 42)

a. Orient the CSM +X-axis along the retrograde local horizontal (lunar reference).
b. Perform CSM +X translation retrograde to target for a 20-n. mi. perilune.
c. Execute LM jettison.
d. Perform CSM -X translation posigrade to null the original maneuver and to return the CSM to a targeted trajectory with a higher perilune.
e. ΔV targets and gimbal angles are ground computed.

---

[a]The procedures described may be used for any jettison of the LM during TLC. These situations include the CSM-only lunar flyby, the CSM-only LOI, and the CSM-only perilune plus 2-hour aborts. Relative motion analysis has not been performed for the latter two cases, but no recontact problems are apparent. If the LM is targeted to impact the moon in step b, no recontact with the CSM will occur, and return to earth is not possible.

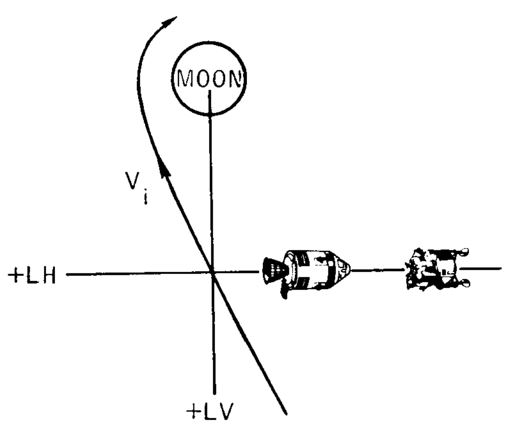
LM JETTISON ATTITUDE



LVLH CSM ATTITUDE

P = 180	Y = 000
Y = 000	P = 180
R = 000/180	R = 000/180

LM JETTISON FOR 20-N. MI. PERILUNE



- PERFORM CSM +X RCS TO TARGET FOR 20-N. MI. PERILUNE
- JETTISON THE LM
- PERFORM CSM -X RCS TO NULL THE ORIGINAL MANEUVER
- ΔV TARGETS AND GIMBAL ANGLES ARE GROUND COMPUTED

Figure 41.- Case: CSM/LM separation; condition: LM jettison during TLC.

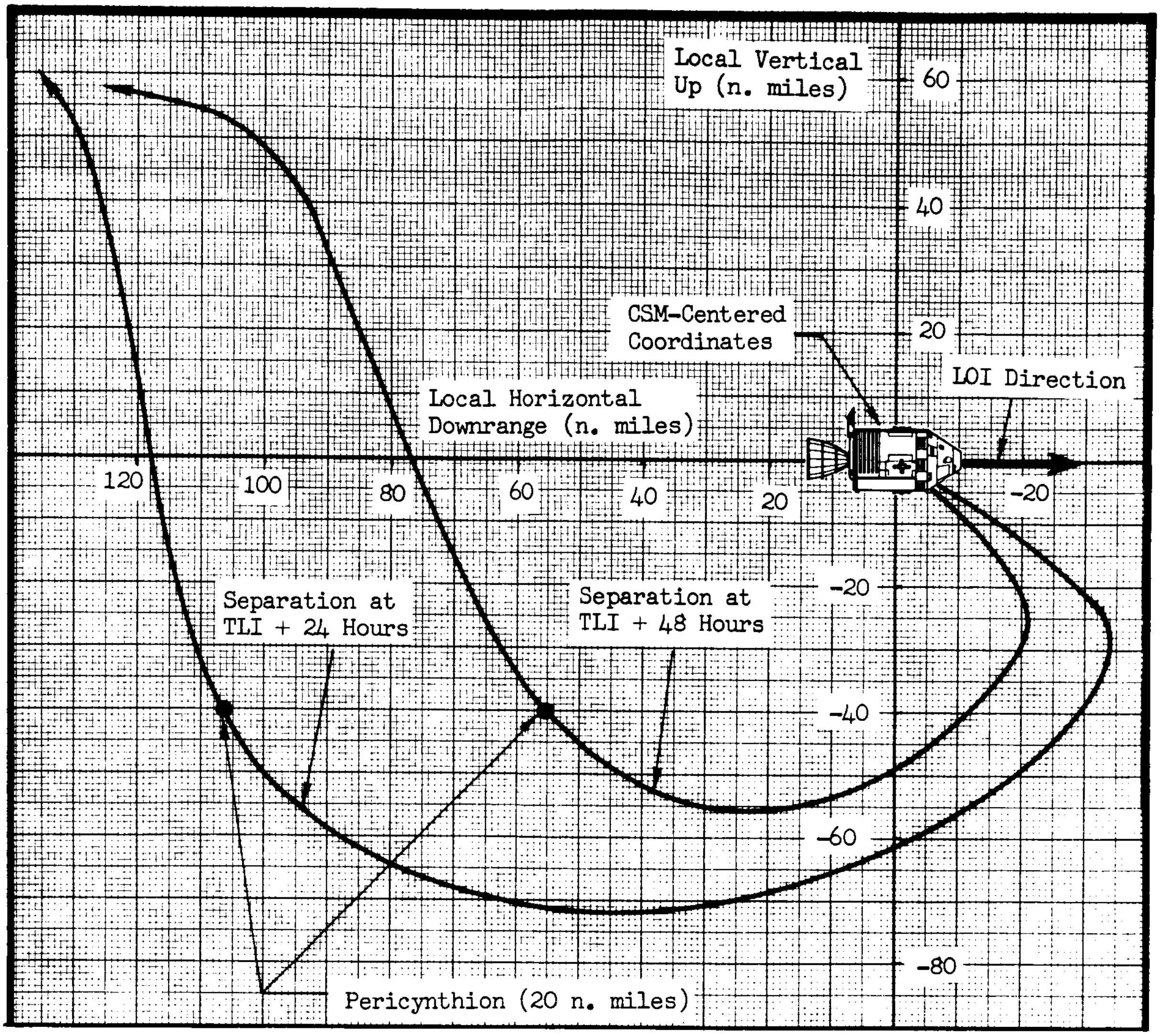


Figure 42.- Relative motion for LM jettison during TLC.

6.2.3.2 LM jettison during TEC - presented in section 8.1.1

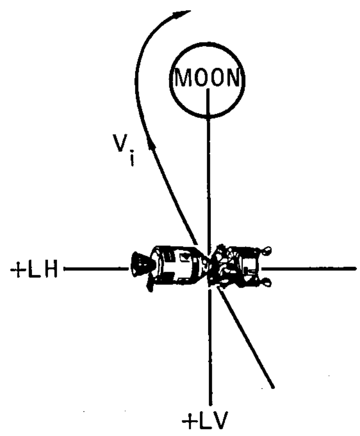
6.3 Alternate missions during TLC

6.3.1 LM jettison during translunar coast - presented in section 6.2.3.1

6.3.2 LM staging during translunar coast - same procedure as LM jettison during translunar coast (figs. 43 and 44).

a. Orient the CSM +X-axis along the retrograde local horizontal (lunar reference).
b. Perform CSM +X translation retrograde to target for a <u>20-n. mi.</u> perilune.
c. Execute DPS staging.
d. Perform LM +X translation posigrade to null the original manuever and to return the CSM/LM to a trajectory with a 60-n. mi. perilune.

DOCKED LM STAGING ATTITUDE

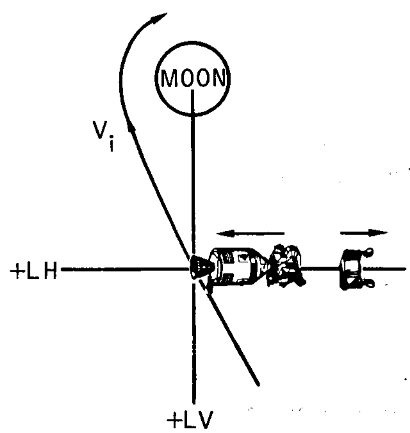


LVLH CSM ATTITUDE

P = 180	Y = 000
Y = 000	P = 180
R = 000/180	R = 000/180

- PERFORM CSM +X RCS TO TARGET FOR A 20-N. MI. PERILUNE

LM STAGING



LVLH CSM ATTITUDE

Y = 000
P = ~090
R = 000/180

- EXECUTE LM STAGING
- PERFORM LM +X RCS TO NULL THE ORIGINAL MANEUVER
- ΔV TARGETS AND GIMBAL ANGLES ARE GROUND COMPUTED

Figure 43.- Case: CSM/LM separation; condition: alternate mission-docked LM staging during translunar coast.

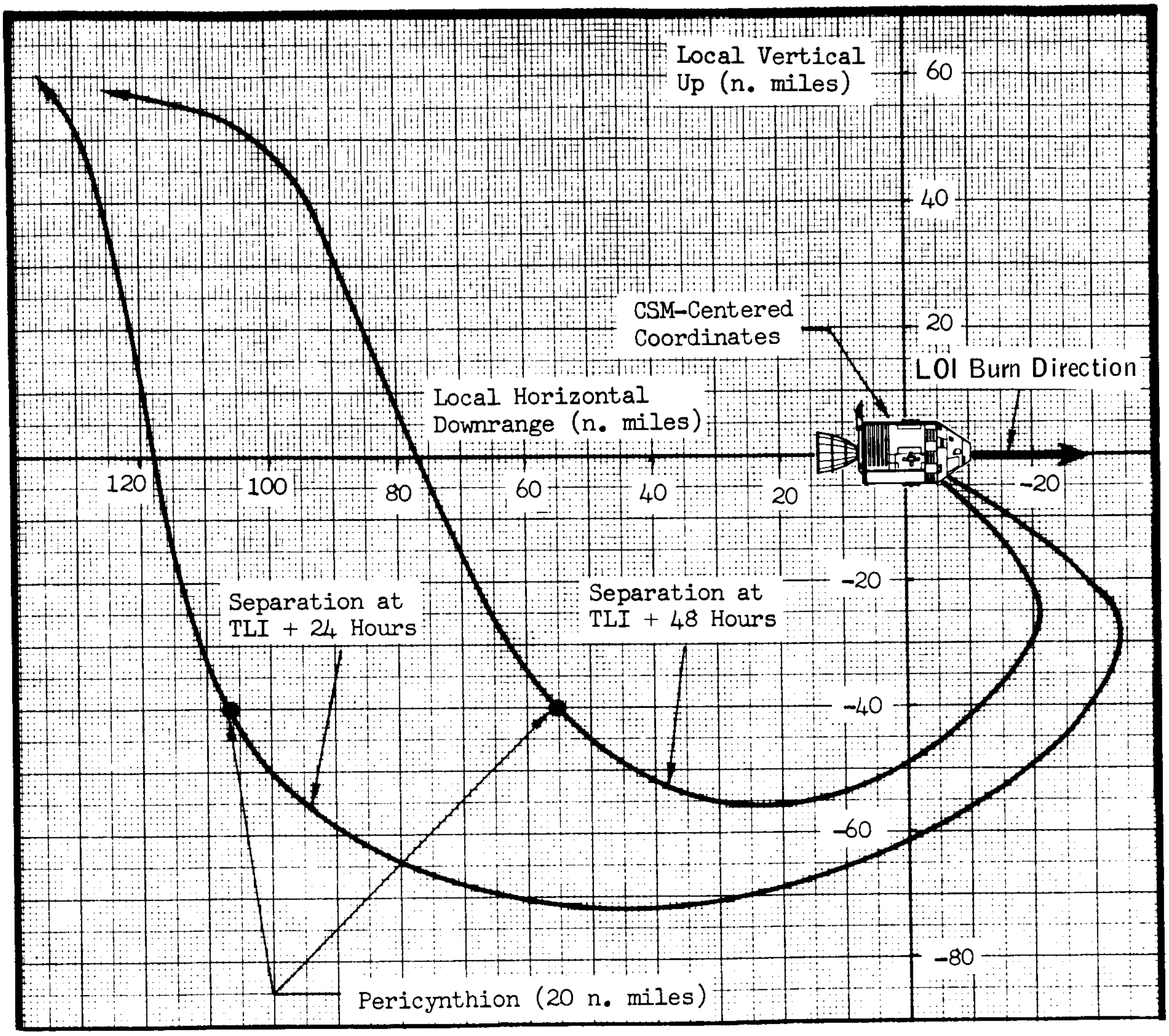


Figure 44.- Relative motion for DPS staging during TLC.

6.3.3 Lunar flyby with the LM - same procedure as alternate mission from TEC - unmanned APS (section 8.2)

7.0 LUNAR ORBIT PHASE

7.1 Nominal separation procedures during lunar orbit

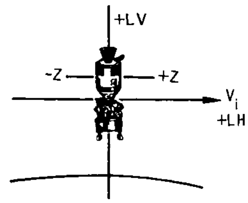
7.1.1 LM undocking (figs. 45 through 48)

Time,[a] hr:min:sec, g.e.t.	Event
107:54:22	For LM undocking, the CSM +X-axis is alined with the negative radius vector (apex toward moon), and the +Z-axis is alined with V_i, heads pointed up-range at a g.e.t. of $107^h54^m22^s$. The CSM will separate from the LM using the radial soft undocking technique. The docking probe capture latches will be used to help minimize separation ΔV perturbations. Undocking is performed in revolution 13 at $107^h54^m22^s$ g.e.t.,[a] with a central angle of 90° prior to the CSM separation maneuver. After undocking, the CSM stationkeeps with the LM at a distance of 40 feet and inertially maintains the radial undocking attitude. The undocking maneuver should not impart any ΔV to the LM. All stationkeeping should be performed by the CSM. The LM does not perform any translation maneuvers, unless required. The LM orients to an eye-to-eye attitude with the CSM by performing a crew pitch-up maneuver to aline the LM +Z-axis with the positive radius vector.

[a]For a nominal November 14, 1969, launch (ref. 5).

Time,[a] hr:min:sec, g.e.t.	Event
108:24:22	The CSM performs -Z RCS translation (radially downward) for a $\Delta V = 2.5$ fps ($\Delta t = 15.8$ sec). The CSM +X-axis is alined with the retrograde LH in a heads-down attitude. No attitude maneuver should be required at this time because the CSM/LM radial undocking attitude was the inertial separation burn attitude. The CSM separation burn ($108^h24^m22^s$) occurs at a central angle of 180° prior to DOI, which occurs at $109^h23^m00^s$ g.e.t.

LM UNDOCKING ATTITUDE AT 107h54m22s[a]



LVLH CSM ATTITUDE

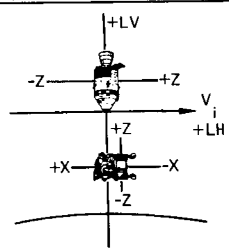
P = -090	Y = 000
Y = 000	P = -090
R = 180	R = 180

CSM GIMBALS

R (OGA) = 180.0
P (IGA) = 284.4
Y (MGA) = 000.0
LANDING SITE REFSMMAT (ref. 4)

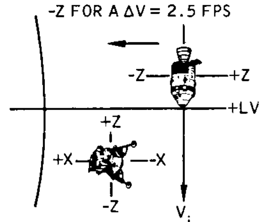
- CSM PERFORMS "SOFT" UNDOCKING FROM LM IN RADIAL ATTITUDE, HEADS POINTED UP RANGE
- CSM PERFORMS STATIONKEEPING AT 40-FT DISTANCE AND INERTIALLY MAINTAINS RADIAL UNDOCKING ATTITUDE UNTIL CSM SEPARATION BURN APPROXIMATELY 30 MIN LATER

CSM/LM EYE TO EYE ATTITUDE



- AFTER UNDOCKING, THE LM ORIENTS TO AN EYE TO EYE ATTITUDE WITH THE CSM BY PERFORMING A CREW PITCH UP MANEUVER TO ALINE THE LM +Z AXIS WITH THE POSITIVE RADIUS VECTOR

CSM SEPARATION BURN ATTITUDE AT 108h24m22s[a]



LVLH CSM ATTITUDE

P = 000	Y = 000
Y = 000	P = 000
R = 180	R = 180

CSM GIMBALS

R (OGA) = 180.0
P (IGA) = 284.4
Y (MGA) = 000.0
LANDING SITE REFSMMAT (ref. 4)

- CSM PERFORMS -Z RCS TRANSLATION FOR A ΔV = 2.5 FPS, HEADS-DOWN ATTITUDE
- LM IS LOCATED APPROXIMATELY 165 AHEAD AND 67 FEET BELOW THE CSM, ASSUMING THE CSM OR LM HAS NOT PERFORMED ANY TRANSLATIONAL MANEUVERS AFTER UNDOCKING AND ESTABLISHING THE 40 FOOT STATION-KEEPING DISTANCE

[a]FOR A NOMINAL NOVEMBER 14, 1969 LAUNCH.

Figure 45.- Case: CSM/LM separation; condition: nominal LM undocking.

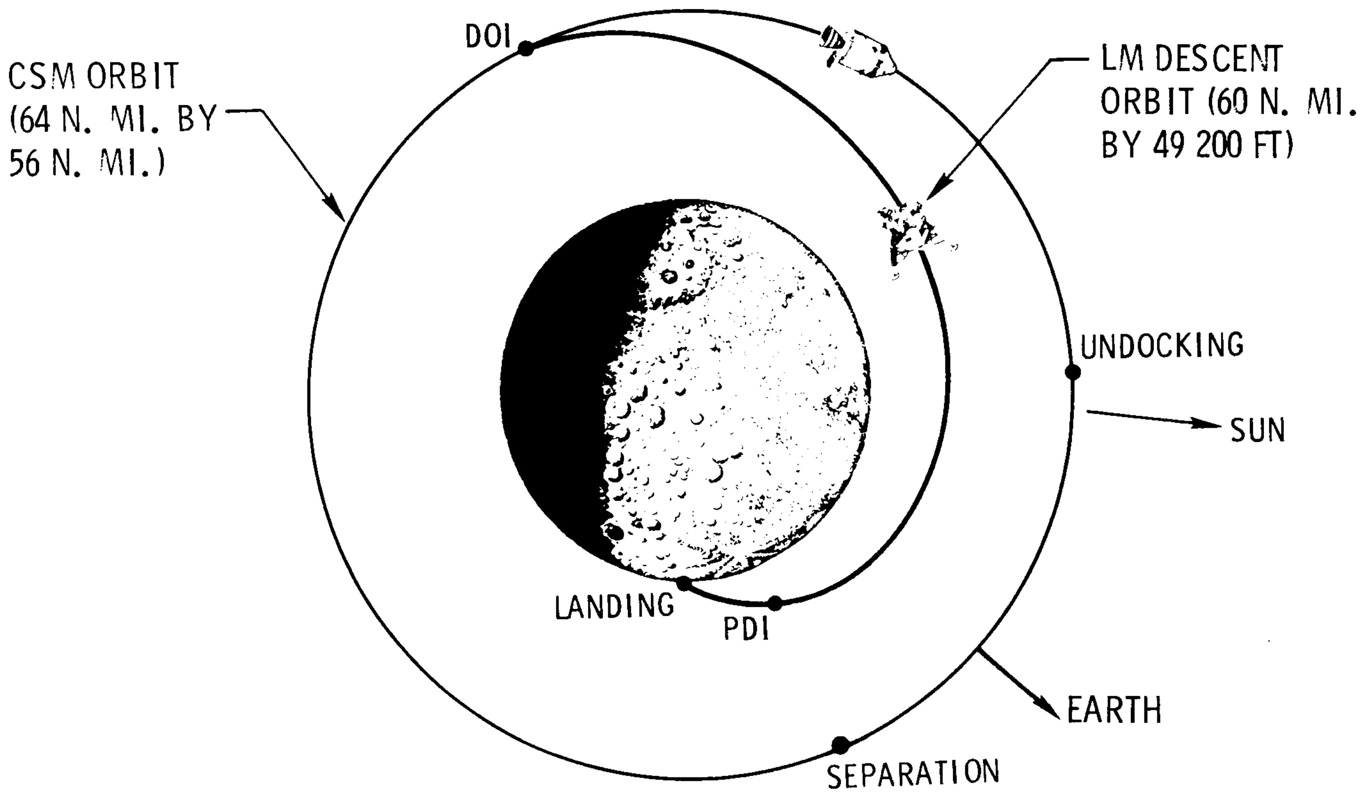


Figure 46.- Lunar descent orbital devents. (ref. 5)

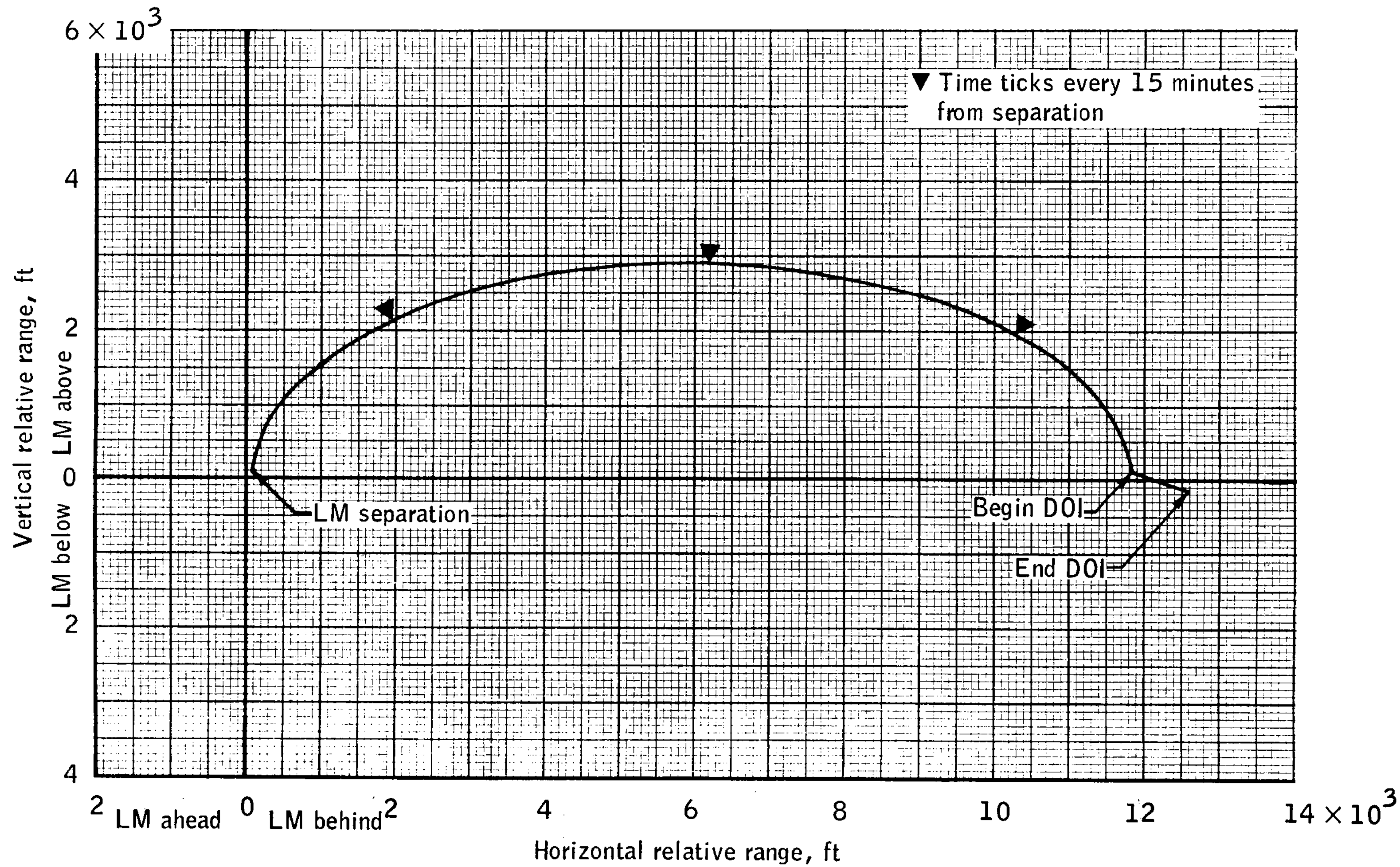


Figure 47.- LM-CSM relative motion from separation to DOI. (ref. 5)

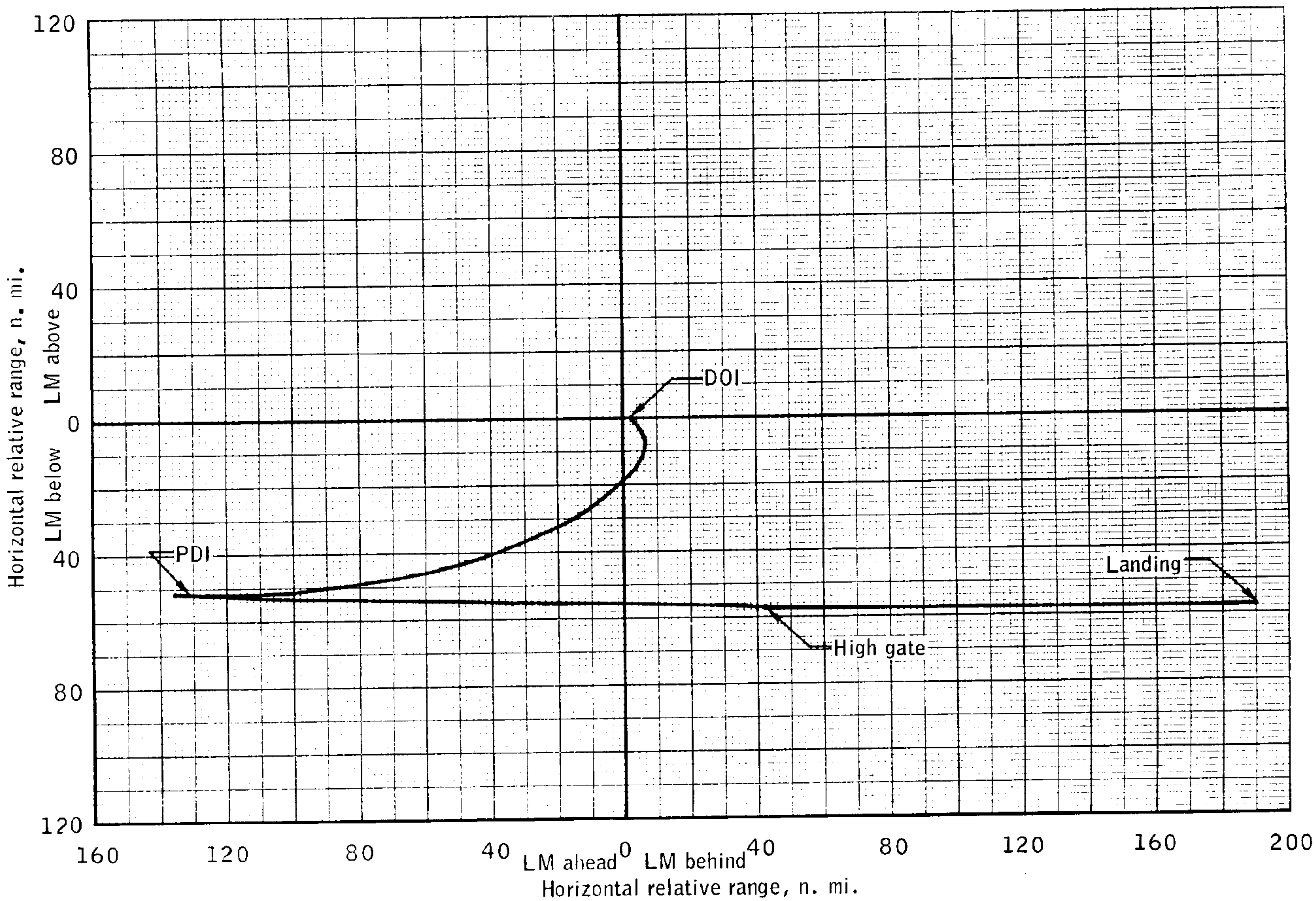


Figure 48.- LM-CSM relative motion (CSM centered) from DOI to landing. (ref. 5)

7.1.2 Nominal LM lift-off from lunar surface (figs. 49, 50, and 51)

Time,[a] hr:min:sec, g.e.t.	Event
142:01:17.9	LM lift-off occurs. Initiate vertical rise phase of ascent. LM Z-body axis is rotated to the desired azimuth. Vertical rise phase ends when guidance switches to the orbital insertion phase for radial rates greater than 40 fps.
142:02:27.9	End vertical rise phase; begin orbit insertion phase. Ascent burn duration = 10 seconds; ΔV = 107.7 fps. LM pitchover profile begins at a radial rate of approximately 50 fps.
142:08:27.9	LM insertion occurs. LM ascent burn duration is 430.0 seconds; ΔV = 6046.2 fps. The nominal lunar lift-off procedure is taken from reference 5.

[a]For a nominal November 14, 1969, launch (ref. 5).

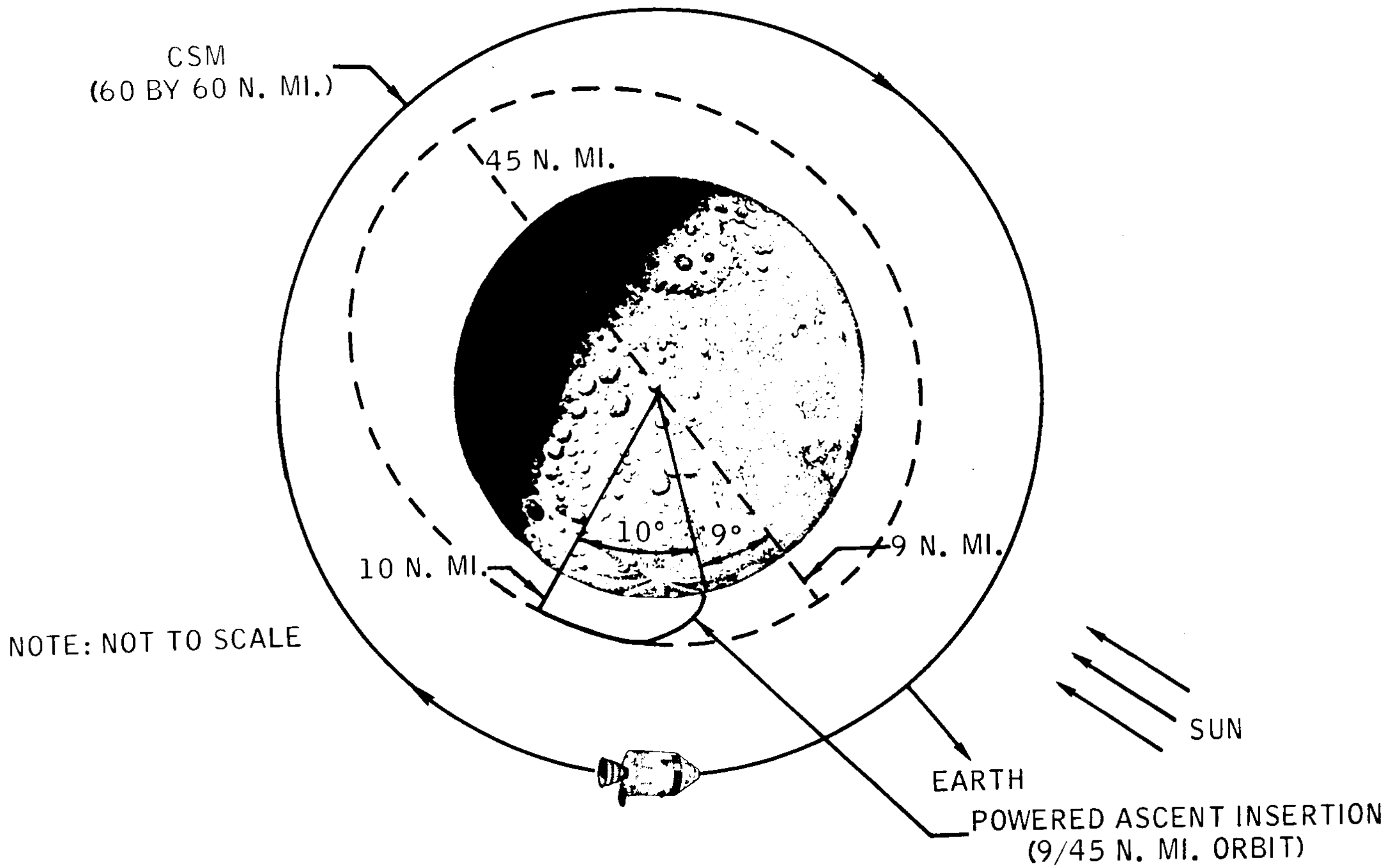


Figure 49.- LM ascent profile. (ref. 5)

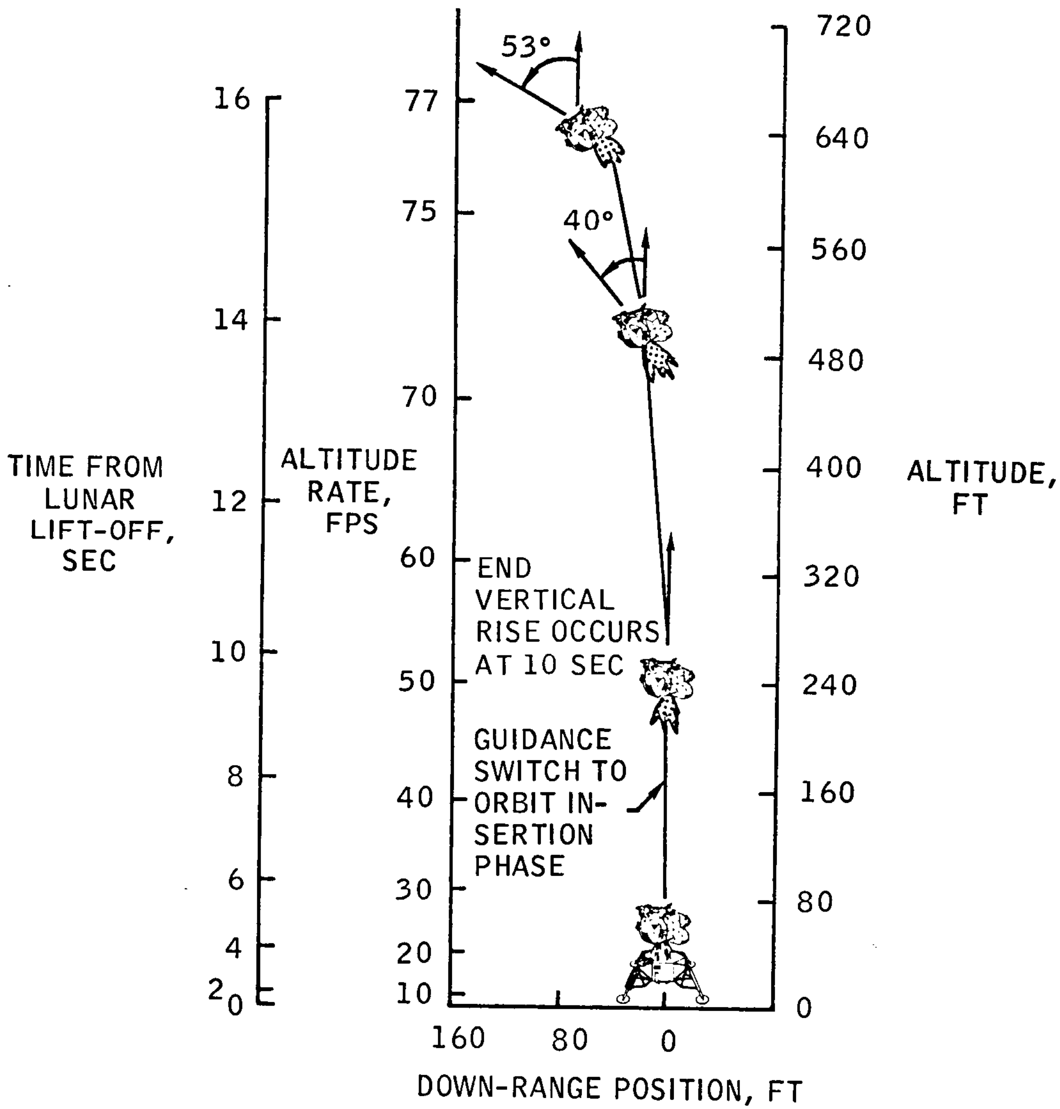


Figure 50.- LM vertical rise phase. (ref. 5)

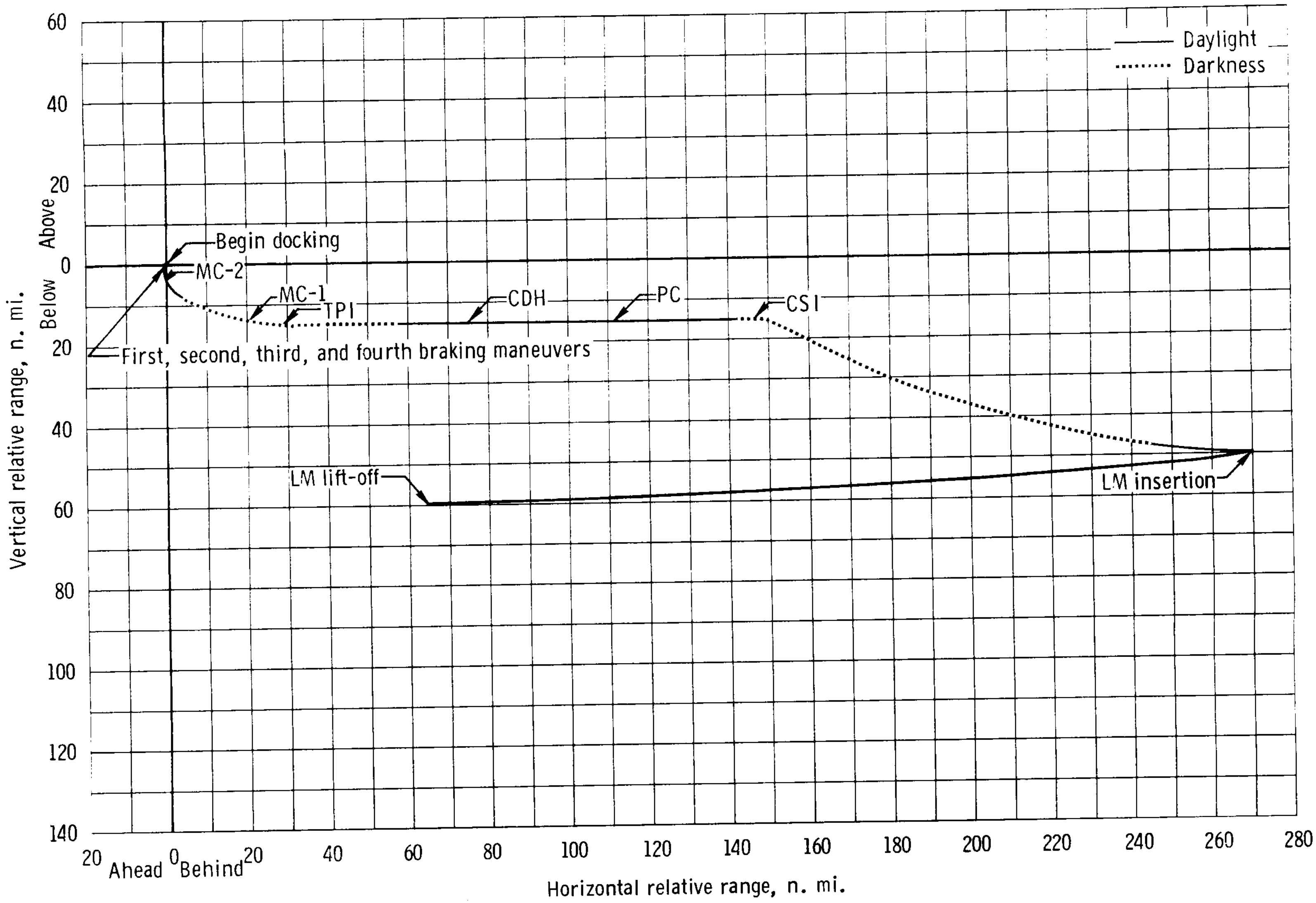


Figure 51. - LM/CSM relative motion, CSM centered, from LM lift-off through docking (ref. 5).

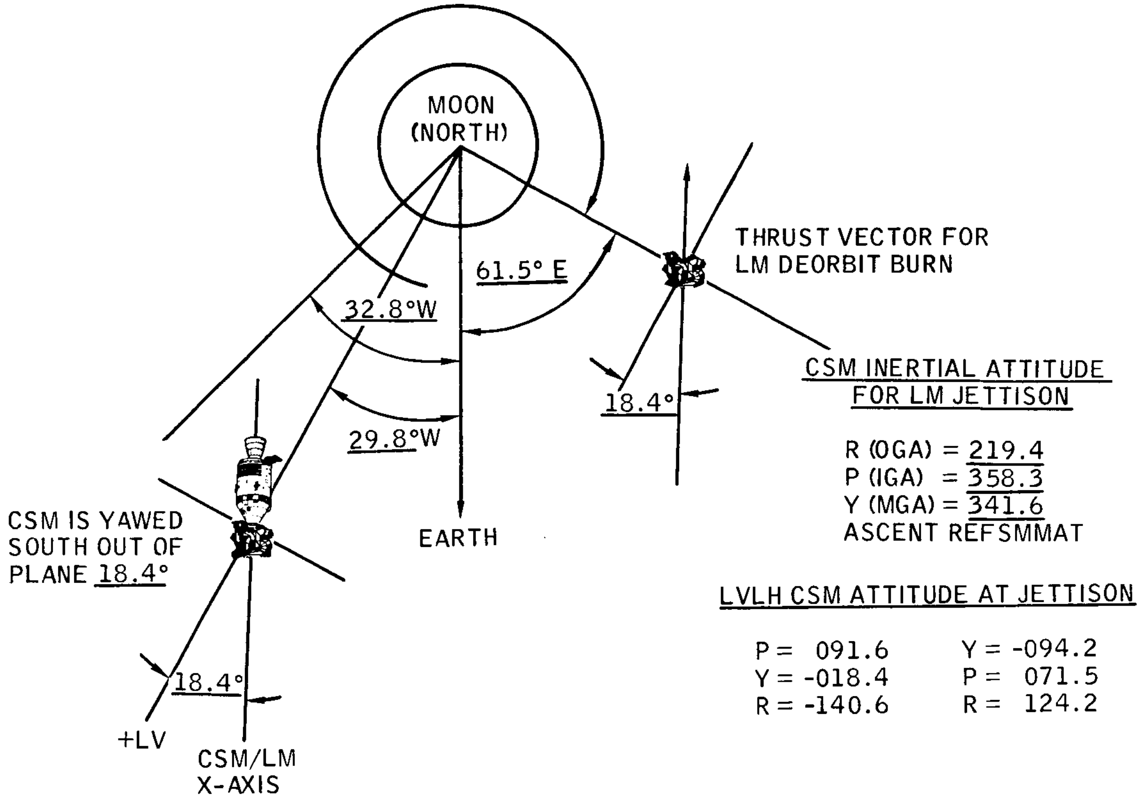
7.1.3 Nominal LM ascent stage jettison and deorbit timeline (figs. 52, 53, and 54)

Time,[a] hr:min:sec, g.e.t.	Event
145:40:00	CSM/LM docking occurs. The crew configures LM for jettison 2^h17^m after docking. Orient the CSM/LM to the inertial LM deorbit burn attitude. CSM gimbals for this attitude are R(OGA) = 219.4°, P(IGA) = 358.3°, and Y(MGA) = 341.6° (ascent REFSMMAT). At the time of LM jettison, the CSM +X-axis will be alined near the positive radius vector and yawed south out of plane approximately 18.4°. The CSM LVLH attitude at the time of LM jettison ($147^h57^m00^s$) is is pitch = 91.6°, yaw = -18.4°, and roll = -140.6°. The LM will be jettisoned radially outward (above the CSM) and out of plane toward the south.
147:57:00	Execute LM jettison at 29.8°W longitude, approximately 3/4 orbit prior to the LM deorbit burn. Total relative ΔV imparted immediately at jettison is approximately 0.45 fps for an unpressurized tunnel to 2.2 fps for a tunnel pressure of 5 psi. Immediately after LM jettison, the CSM orients to the separation maneuver attitude: P(IGA) = 356.3°, Y(MGA) = 0.0°, and R(OGA) = 180°. At the time of the separation maneuver ($147^h58^m01^s$), the CSM LVLH attitude is pitch = 90°, yaw = 0°, and roll = 180°.
147:58:01	Perform CSM two-jet +Z RCS translation retrograde for a ΔV = 1.0 fps, Δt = 6.1 seconds. The CSM separation maneuver is executed at approximately 32.8°W longitude, with the CSM +X-axis alined with the positive radius vector and the +Z-axis alined with the retrograde LH (heads pointed down range).

[a]For a nominal November 14, 1969, launch.

Time,[a] hr:min:sec, g.e.t.	Event
149:24:41.2	The LM initiates the +X RCS retrograde burn at 63.7°E longitude for a total ΔV = 189.7 fps. The inertial LM deorbit burn attitude is Y(OGA) = 80.6°, P(IGA) = 178.3°, and R(MGA) = 18.4°. No LM attitude maneuver should be required at this time because the LM was jettisoned in the inertial deorbit burn attitude. The burn targets are ΔV_x = 180 fps, ΔV_y = 60 fps, ΔV_z = 0 fps. The RCS burn Δt = 83.8 seconds. The impulsive ΔV point of the burn occurs at 61.5°E longitude. The CSM gimbals for forward window viewing of the LM ascent stage at deorbit burn ignition are R(OGA) = 282.3°, P(IGA) = 170.8°, and Y(MGA) = 20°. The corresponding LVLH attitudes for the CSM at this time are yaw 159.7°, Pitch 8.9°, and roll 99.2°. In the event the LM deorbit burn is not executed, relative motion indicates that the CSM will continue to increase in downrange displacement from the LM (fig. 54). The CSM will be in the correct relative position with respect to the LM for a nominal or early TEI burn. The LM passes below the CSM at a range of approximately 50 n. mi. just prior to impact.
149:52:50.5	The deorbit burn impacts the LM on the lunar surface near 3.28°S and 23.38°W, approximately 5 n. mi. south of site 7, 28 minutes 9.3 seconds after ignition.
172:21:14.7	CSM performs TEI.

[a]For a nominal November 14, 1969, launch.

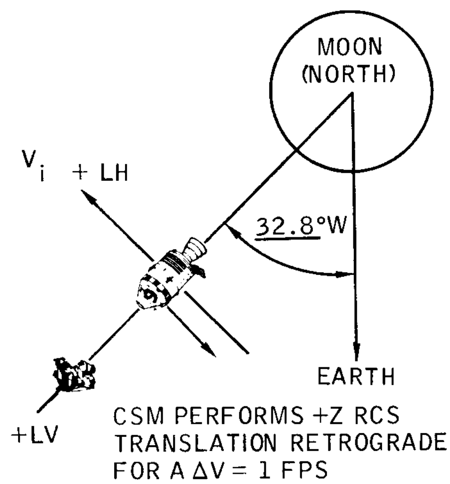


- ORIENT THE CSM/LM TO THE INERTIAL LM DEORBIT BURN ATTITUDE
- THE LM DEORBIT BURN THRUST VECTOR IS RETROGRADE WITH A NORTH OUT OF PLANE COMPONENT; THEREFORE, THE JETTISON ATTITUDE IS OUT OF PLANE
- AT THE TIME OF LM JETTISON, THE CSM +X-AXIS IS ALINED NEAR THE POSITIVE RADIUS VECTOR, AND YAWED SOUTH OUT OF PLANE APPROXIMATELY 18.4°.

PERFORM LM JETTISON AT 29.8°W LONGITUDE, APPROXIMATELY 3/4 ORBIT PRIOR TO THE DEORBIT BURN. THE CSM DOES NOT PERFORM STATIONKEEPING

(a) LM ascent stage jettison attitude at $147^h 57^m 00^s$.

Figure 52.- Case: CSM/LM ascent stage separation; condition: nominal LM ascent stage jettison prior to TEI.



CSM INERTIAL ATTITUDE FOR SEPARATION MANEUVER

R (OGA) = 180.0
P (IGA) = 353.6
Y (MGA) = 000.0
ASCENT REFSMMAT (ref. 4)

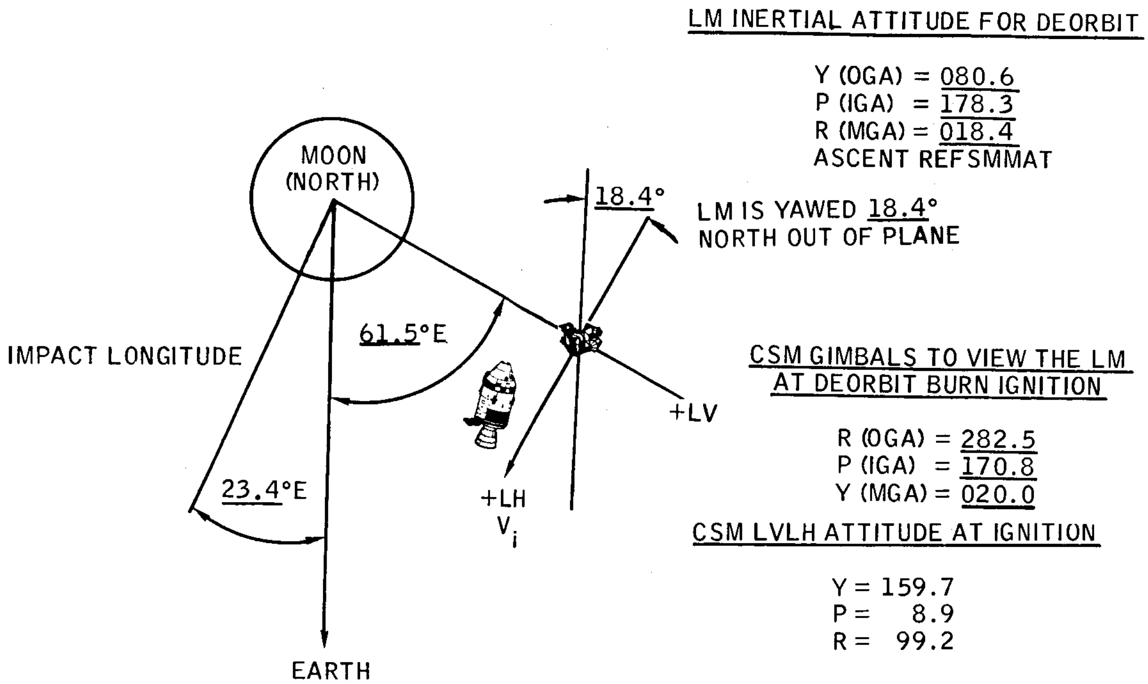
LVLH CSM ATTITUDE

P = 090	Y = 000
Y = 000	P = 090
R = 180	R = 180

- FOLLOWING LM JETTISON, THE CSM ORIENTS TO THE ATTITUDE SHOWN ABOVE. (NOTE THAT THE ATTITUDE SHOWN ABOVE IS NEAR THE ATTITUDE FOR LM JETTISON, THEREFORE MINIMUM ORIENTATION IS REQUIRED).
- PERFORM CSM +Z RCS TRANSLATION RETROGRADE FOR A ΔV = 1 FPS AT 32.8°W LONGITUDE, APPROXIMATELY ONE MINUTE AFTER LM JETTISON

(b) CSM separation maneuver attitude at $147^h58^m01^s$.

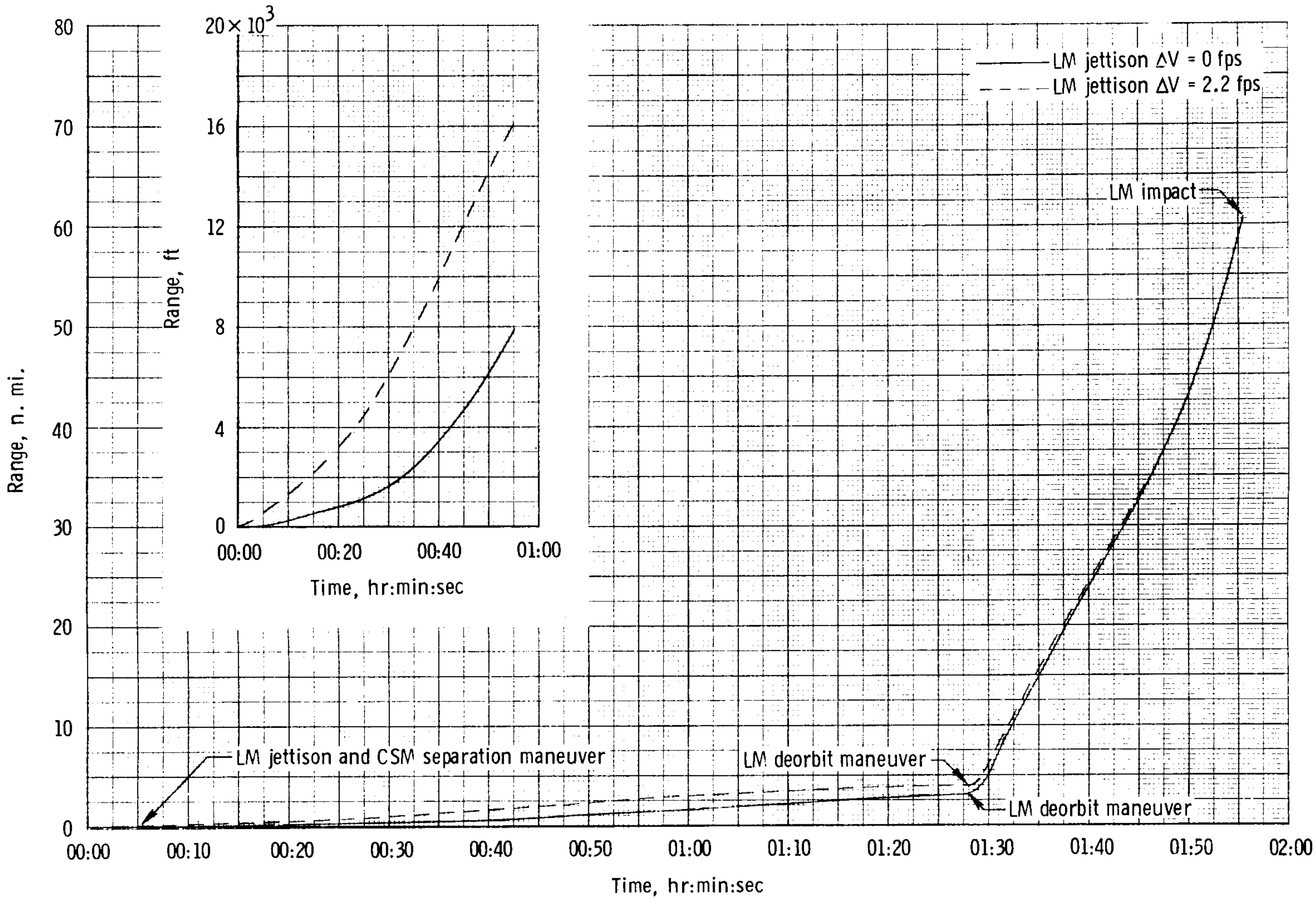
Figure 52.- Continued.



- LM EXECUTES +X RCS RETROGRADE BURN FOR A ΔV_X = -180 FPS, ΔV_Y = 60 FPS AND ΔV_Z = 0 FPS. TOTAL ΔV = 189.7 FPS. BURN ΔT = 83.8 SEC
- THE LM DEORBIT BURN IGNITION OCCURS AT 63.7°E TO IMPACT NEAR 3.28°S AND 23.38°N. THE MIDPOINT OF THE BURN IS APPROXIMATELY 61.5°E LONGITUDE

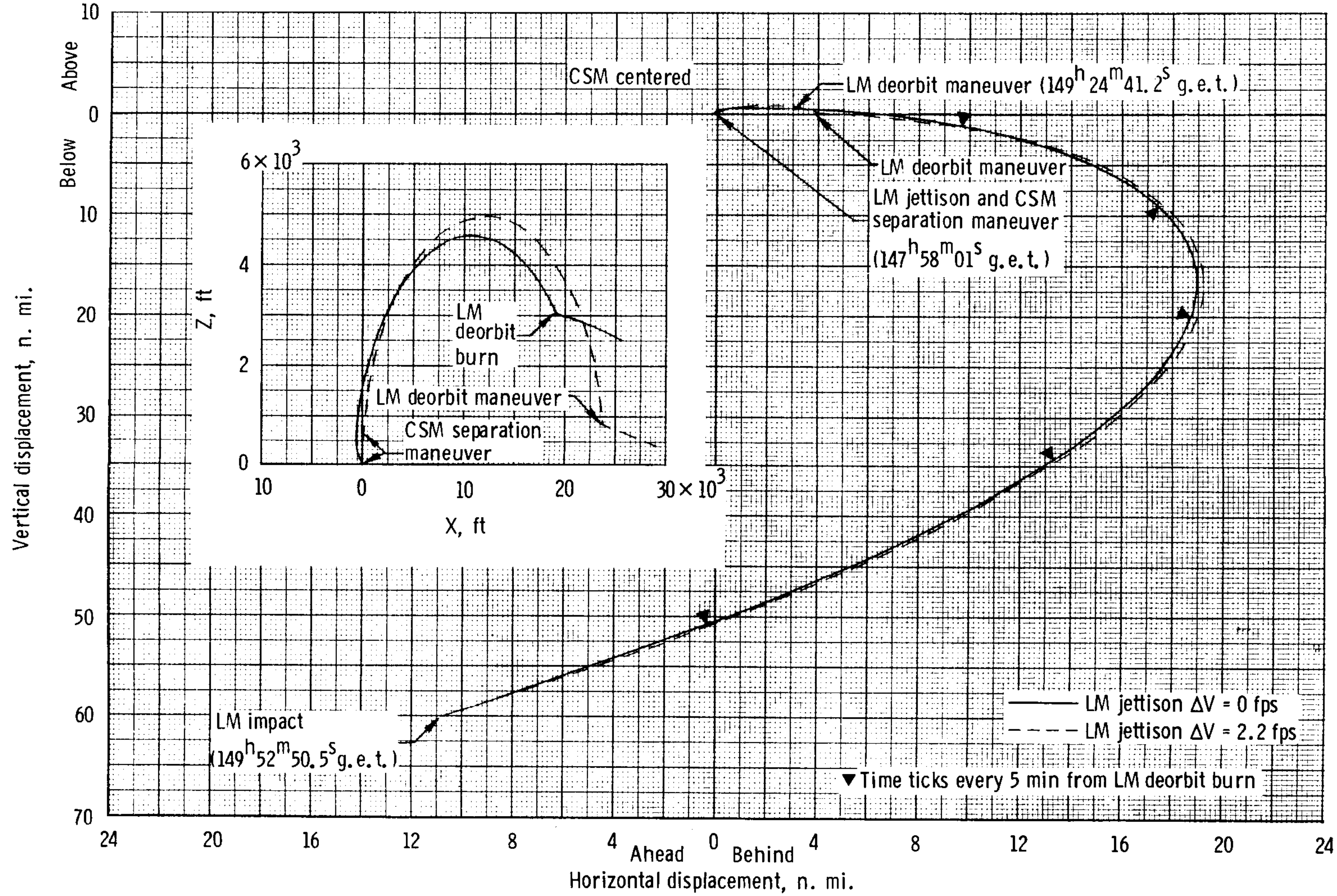
(c) LM deorbit burn attitude at $149^h 24^m 41.2^s$.

Figure 52.- Concluded.



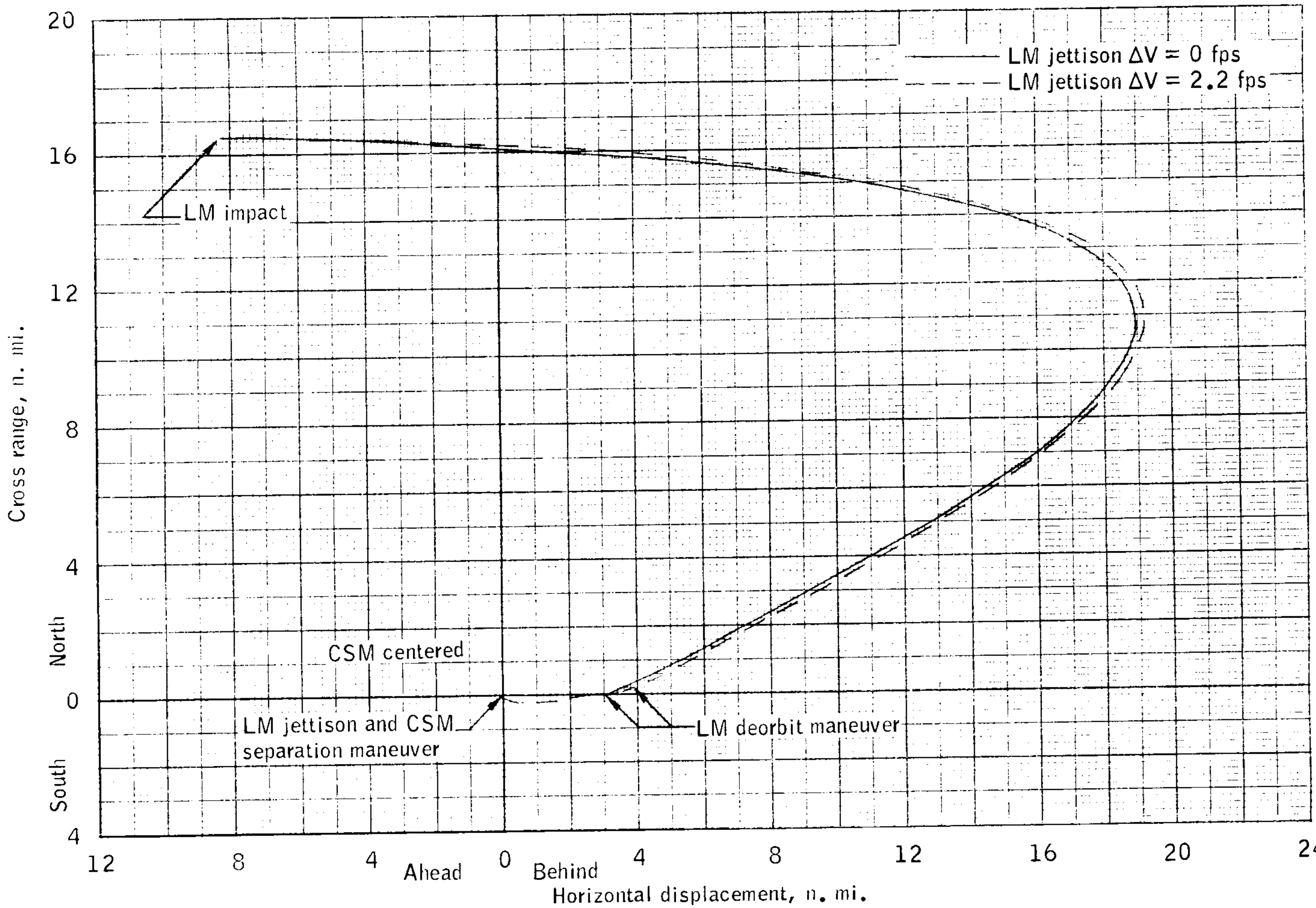
(a) Range versus time from LM jettison.

Figure 53. - Motion of the LM relative to the CSM for the LM jettison, CSM separation, and LM deorbit maneuvers.



(b) Vertical displacement versus horizontal displacement.

Figure 53. - Continued.



(c) Cross range versus horizontal displacement.

Figure 53.- Concluded.

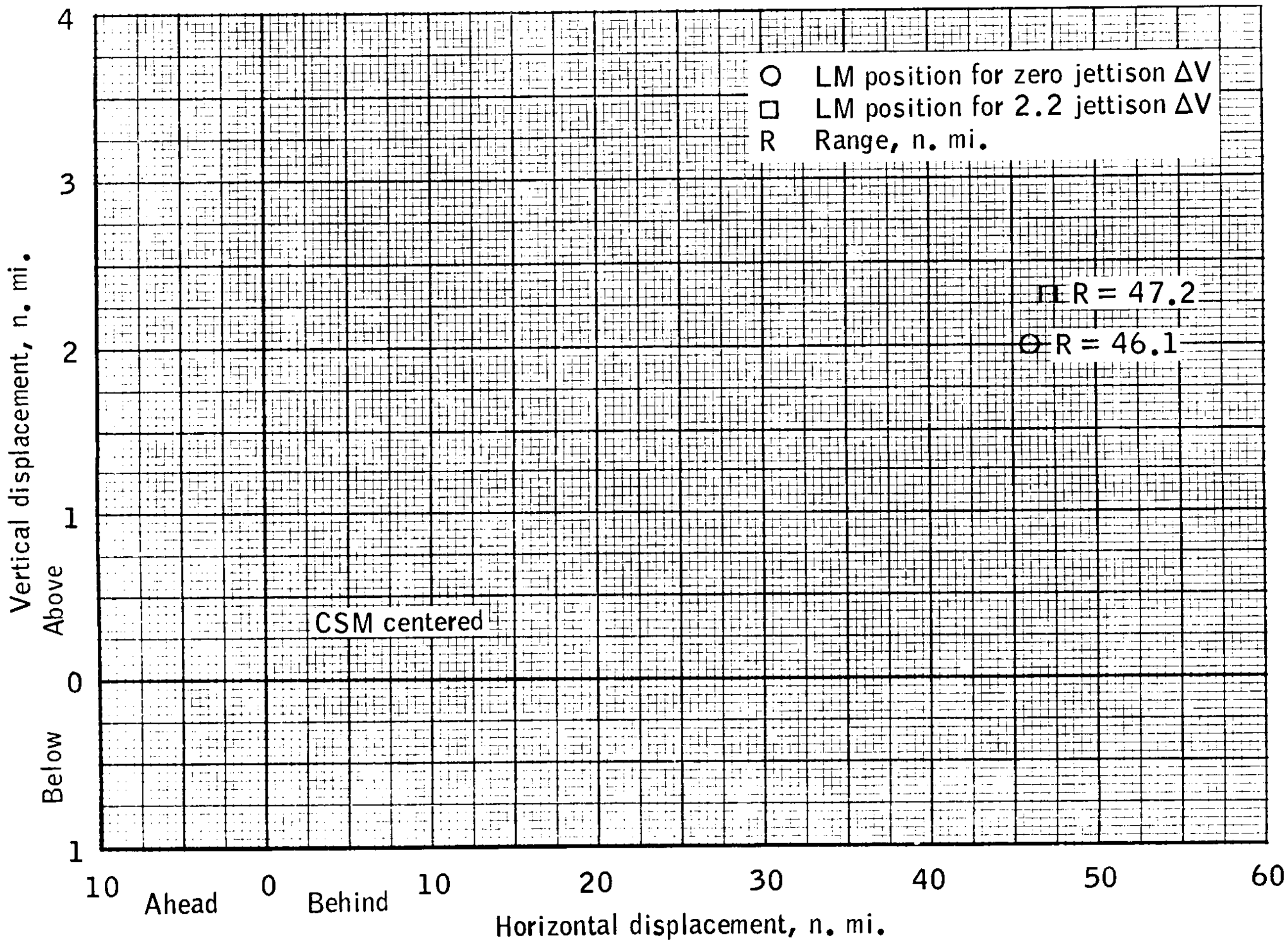


Figure 54.- LM position relative to the CSM at TEI in the event LM deorbit is not performed.

7.2 Aborts during lunar orbit

7.2.1 Contingency TEI - LM ascent stage only or LM ascent/descent stage jettison required (figs. 55 and 56)

a. Orient the CSM +X-axis along the posigrade local horizontal. (Ground computed gimbal angles will be supplied.)
b. Perform LM jettison (CSM in heads-down attitude).
c. Perform CSM -X RCS translation retrograde for a net velocity increment of 1.0 fps.
d. Coast for 1 hour until TEI, minimum of 30 minutes.
e. Execute TEI (posigrade CSM SPS burn).
f. If the LM is to be deorbited, the nominal procedure (section 7.1.3) may be used.

7.2.2 Contingency TEI following nominal LM jettison

After the nominal LM jettison and CSM separation maneuver, the spacecraft may perform TEI at any time, regardless of whether a LM deorbit burn is performed. The LM position relative to the CSM for a no LM deorbit burn case is presented in figure 54.

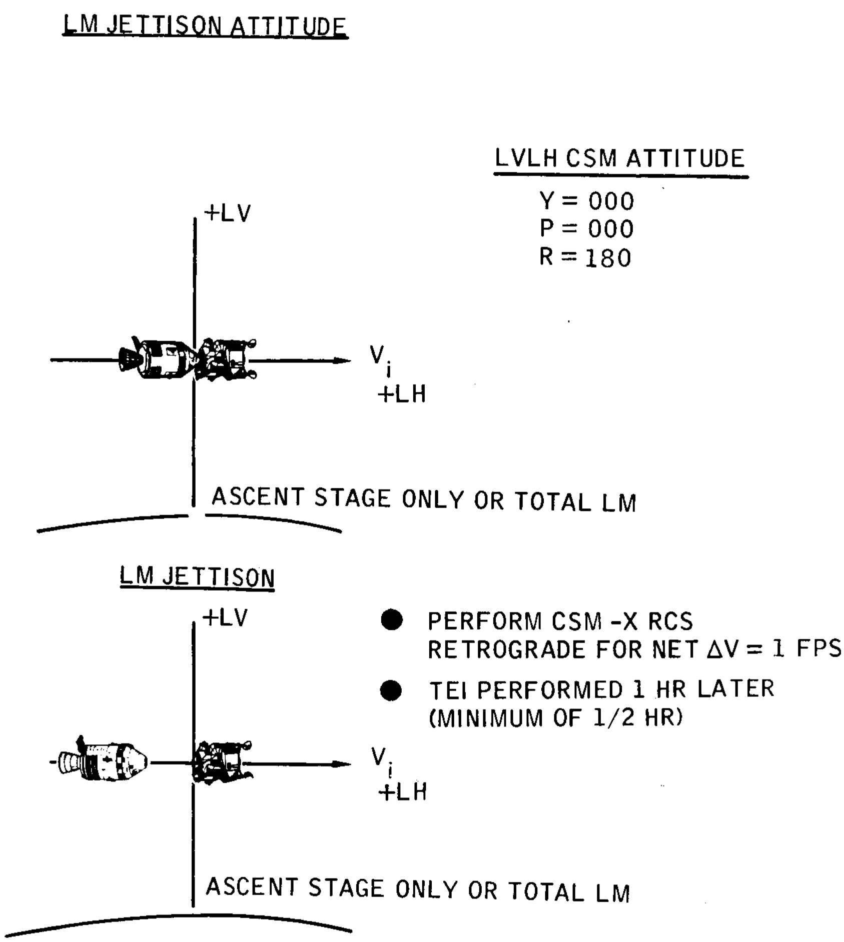


Figure 55.- Case: CSM/LM separation; condition: contingency TEI.

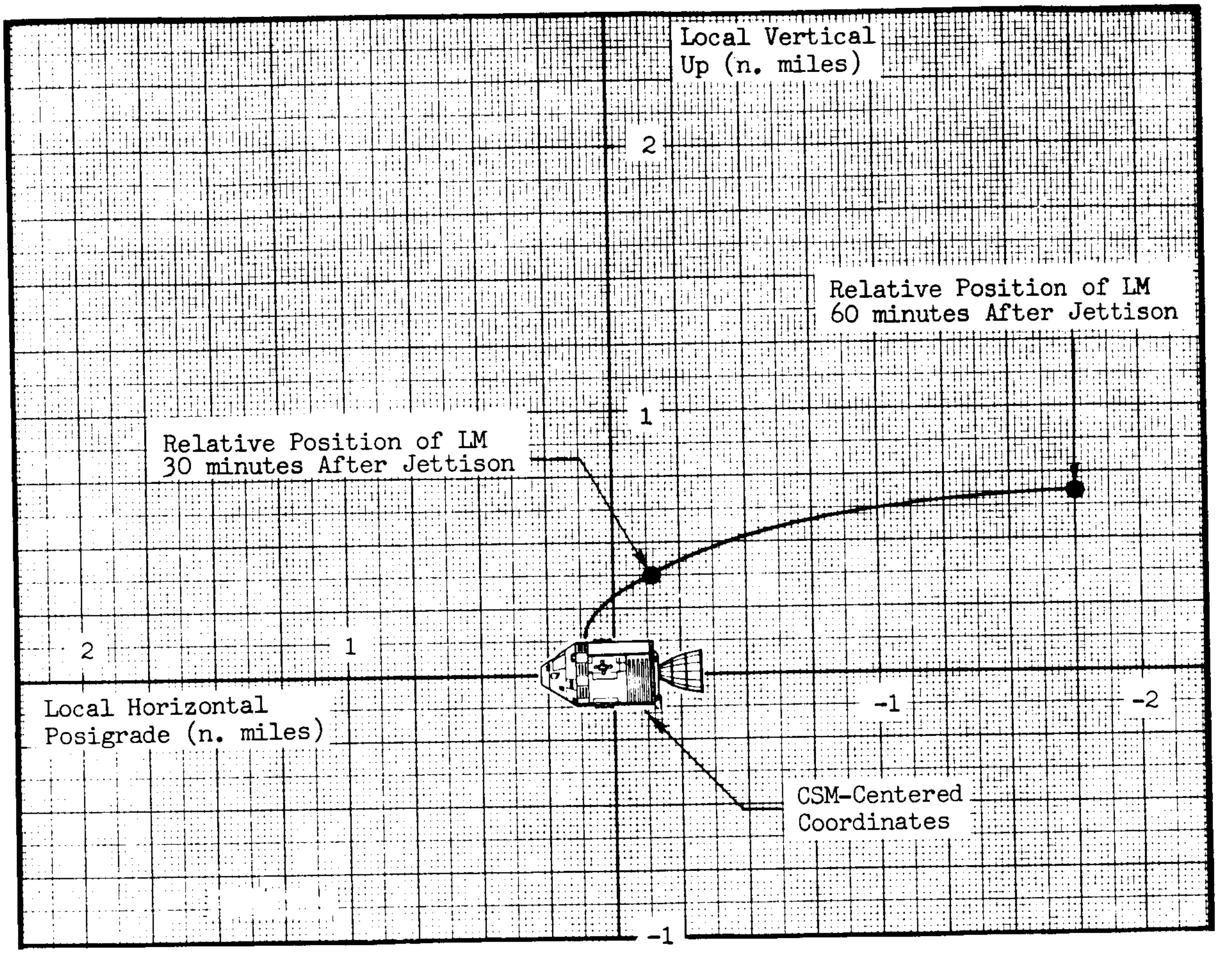


Figure 56.- Relative motion for LM jettison prior to contingency TEI.

7.2.3 LOI aborts (for detailed descriptions of LOI aborts, see ref. 7)

7.2.3.1 Mode I (DPS only)

a. Mode I aborts consist of a single impulse maneuver that inserts the CSM/LM on the transearth trajectory.

b. LM jettison procedures during TEC are presented in section 8.1.1.

7.2.3.2 Mode Ia (DPS + APS)

a. Mode Ia aborts consist of two maneuvers, the first performed with the LM DPS at LOI plus 0.5 hour and the second with the LM APS at LOI plus 2.5 hours.

b. LM staging is planned after the LM DPS maneuver.[a] LM RCS staging is performed as follows.

1. Staging of the LM should be performed during execution of a four-jet 3-second +X RCS translation.
2. The +X translation is initiated and is followed immediately by staging. Continue +X translation for a burn $\Delta t = \underline{3}$ seconds to insure a positive separation rate from the descent stage.

c. The LM APS TEI burn will be performed approximately 2 hours later.

d. LM ascent stage jettison will be performed during TEC; procedures are presented in section 8.1.1.

7.2.3.3 Mode IIa (DPS + APS)

a. Mode IIa aborts consist of two maneuvers; the first (DPS-1) is directed along the negative radius vector (toward moon) at LOI plus 2 hours. The second maneuver (DPS-2) is performed at LOI plus one revolution and consists of a second DPS burn followed as soon as possible by an APS TEI burn.

b. LM staging[b] is planned immediately after the DPS-2 maneuver (see section 7.2.3.2, step b above, for the LM RCS staging procedure).

c. The LM ascent stage is jettisoned after the APS TEI during TEC (section 8.1.1).

---

[a] If it is determined after the DPS maneuver and prior to staging that the TEI ΔV required will be within the capability of and will be performed by the CSM RCS or SPS, then the LM should not be staged. TEI should be executed with the CSM RCS or SPS rather than the LM APS, and then the entire LM should be jettisoned during TEC.

[b] If it is determined prior to staging that the TEI ΔV required will be within the capability of and will be performed by the CSM RCS or SPS, then the LM should not be staged after the DPS-2 maneuver. TEI should be performed with the CSM RCS or SPS rather than the LM APS; and then the entire LM should be jettisoned during TEC.

7.2.3.4 Mode II (DPS only)

a. Mode II aborts consist of two DPS maneuvers; the first (DPS-1) is directed along the negative radius vector (toward moon) at LOI plus 2 hours, and the second (DPS-2) occurs at LOI plus 1 revolution and injects the SC on the trans-earth trajectory.

b. LM jettison is performed during TEC; procedures are presented in section 8.1.1.

7.2.3.5 Mode III (DPS only)

a. Mode III aborts consist of a single DPS maneuver initiated at LOI plus one revolution to inject the SC on a trans-earth trajectory.

b. LM jettison is performed during TEC; procedures are presented in section 8.1.1.

8.0 TEC PHASE

8.1 Aborts during TEC

8.1.1 Early DPS staging or LM jettison during TEC, prior to 3 hours before entry interface (figs. 57 and 58). Utilization of posigrade or retrograde technique is a real-time option.

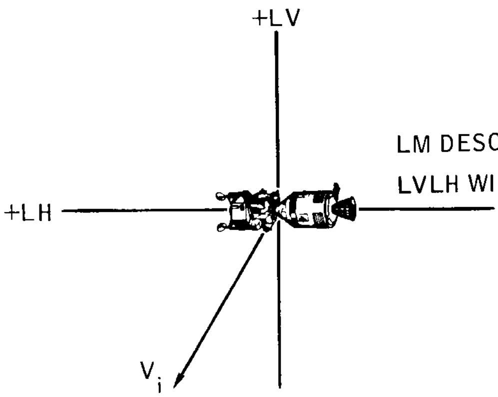
8.1.1.1 LM targeted for a 70-n. mi. or greater vacuum perigee, posigrade jettison technique.

a. Orient the CSM +X-axis along the posigrade local horizontal (earth reference).
b. Perform CSM +X RCS translation posigrade to target for a 70-n. mi. or greater vacuum perigee. (Maneuver ΔV and attitudes are ground computed.)
c. Execute LM jettison or staging.
d. Perform CSM -X RCS translation retrograde to lower the vacuum perigee and to null the first CSM maneuver.
e. The net result of this push-pull sequence is to insert the LM on a trajectory with a 70-n. mi. perigee (avoiding LM entry) and to leave the CSM trajectory undisturbed.
f. Initially, the LM moves ahead of the CSM, then moves into a higher, slower orbit which results in the LM being approximately 80 n. mi. above the CSM and approximately 250 n. mi. behind it when the CSM begins entry. During entry, the CSM slows down and lifts, and the LM passes the CSM approximately 20 n. mi. above it.
g. Note that the minimum separation distance of 20 n. mi. results entirely from the LM being targeted to a 70-n. mi. perigee. If the target perigee is reduced to 50 n. mi., a recontact is possible during entry. If the spacecraft entry guidance results in anything less than full-lift, the minimum separation distance of 20 n. mi. will increase.
h. If the CSM RCS fuel budget is not sufficient to execute a posigrade push-pull maneuver to target the LM to a perigee of 70 n. mi., the same maneuver may be performed in the retrograde direction to insure that the LM enters well up range of the CSM.

8.1.1.2 LM targeted for entry up range of the CSM, retrograde technique

a. Orient the CSM +X-axis in the direction of the retrograde local horizontal (earth reference).
b. Perform CSM +X RCS translation retrograde for a maximum velocity determined by the CSM RCS fuel budget.
c. Execute LM jettison or staging.
d. Perform CSM -X RCS translation posigrade to null the original CSM maneuver.
e. Initially, the LM will translate behind and below the CSM and then below and ahead of it so that it enters before the spacecraft.

STAGING OR JETTISON ATTITUDE
(POSIGRADE TECHNIQUE)



LVLH CSM ATTITUDE

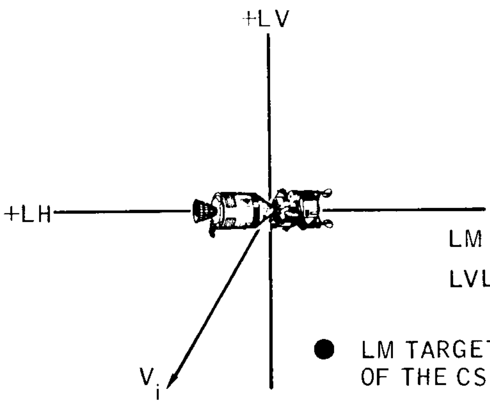
P = 000	Y = 000
Y = 000	P = 000
R = 000/180	R = 000/180

LM DESCENT STAGE ONLY OR TOTAL LM

LVLH WITH RESPECT TO EARTH

- PERFORM CSM +X RCS TO TARGET FOR A 70-N. MI. OR GREATER VACUUM PERIGEE
- EXECUTE LM JETTISON (OR DPS STAGING)
- PERFORM CSM -X RCS TO NULL THE ORIGINAL MANEUVER (OR LM +X RCS IF STAGING WAS PERFORMED)

STAGING OR JETTISON ATTITUDE
(RETROGRADE TECHNIQUE)



LVLH CSM ATTITUDE

P = 180	Y = 000
Y = 000	P = 180
R = 000/180	R = 000/180

LM DESCENT STAGE ONLY OR TOTAL LM

LVLH WITH RESPECT TO EARTH

- LM TARGETED FOR EARTH IMPACT UPRANGE OF THE CSM
- PERFORM CSM +X RCS FOR A ΔV TO BE DETERMINED BY RCS FUEL BUDGET
- EXECUTE LM JETTISON (OR DPS STAGING)
- PERFORM CSM -X RCS TO NULL THE ORIGINAL MANEUVER (OR LM +X RCS IF STAGING WAS PERFORMED)

Figure 57.- Case: CSM/LM separation; condition: early DPS staging or LM jettison during TEC.

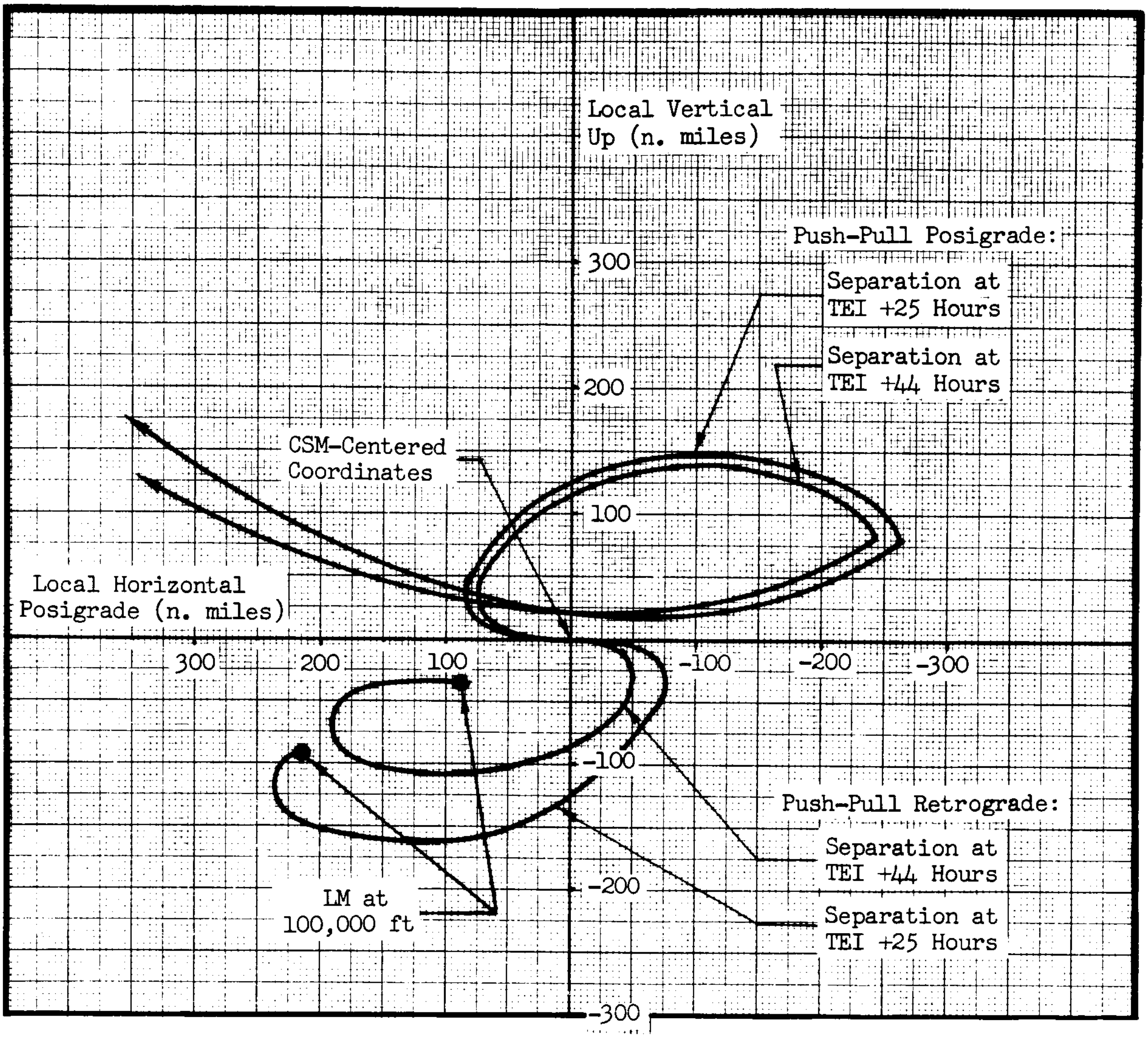


Figure 58.- Relative motion for early DPS staging or LM jettison during TEC.

8.1.2 Late LM jettison during TEC, after 3 hours and before 45 minutes prior to entry interface (figs. 59 and 60)

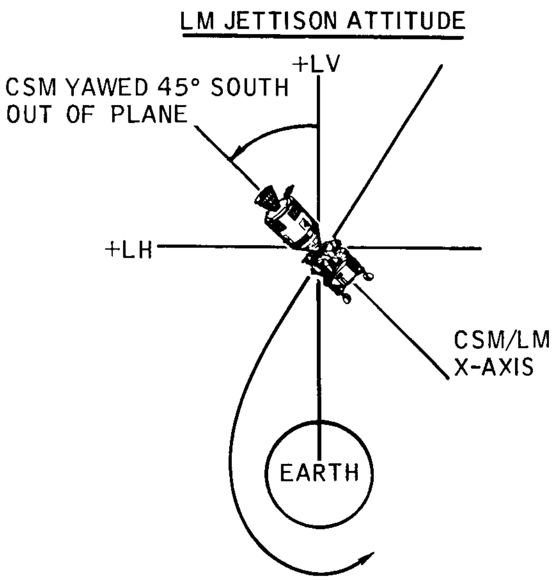
a. If the LM is retained during TEC later than 3 hours prior to entry interface, the following procedure will be used, preferably at EI minus 1 hour. After this time during TEC, the preceding procedures (section 8.1.1) can no longer efficiently produce separation distance for minimum fuel expenditures.

b. Aline the CSM +X-axis with the negative radius vector and yaw 45° out of plane south (CSM apex points south)

c. Execute LM jettison.

d. Perform CSM -X translation for a net velocity increment of 3.0 fps.

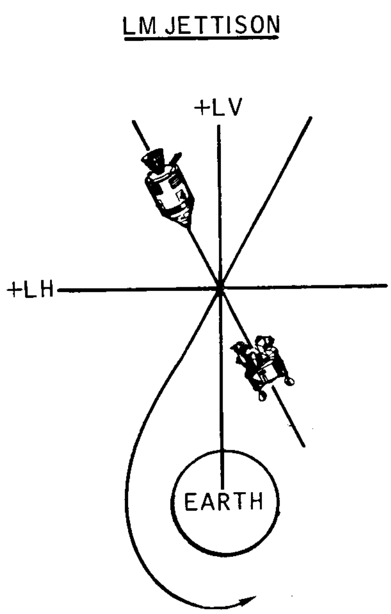
e. The CSM translates behind (retrograde) and out of the orbital plane to the north of the LM.



LVLH CSM ATTITUDE

Y = 090	P = -090
P = -045	Y = 045
R = 000/180	R = 000/180

- ALINE CSM +X-AXIS WITH NEGATIVE RADIUS VECTOR
- CSM YAWS 45° SOUTH OUT OF PLANE



- CSM JETTISONS LM AND PERFORMS -X RCS TRANSLATION FOR A NET $\Delta V = 3$ FPS
- CSM TRANSLATES BEHIND AND NORTH OF THE LM

Figure 59.- Case: CSM/LM separation; condition: late LM jettison during TEC.

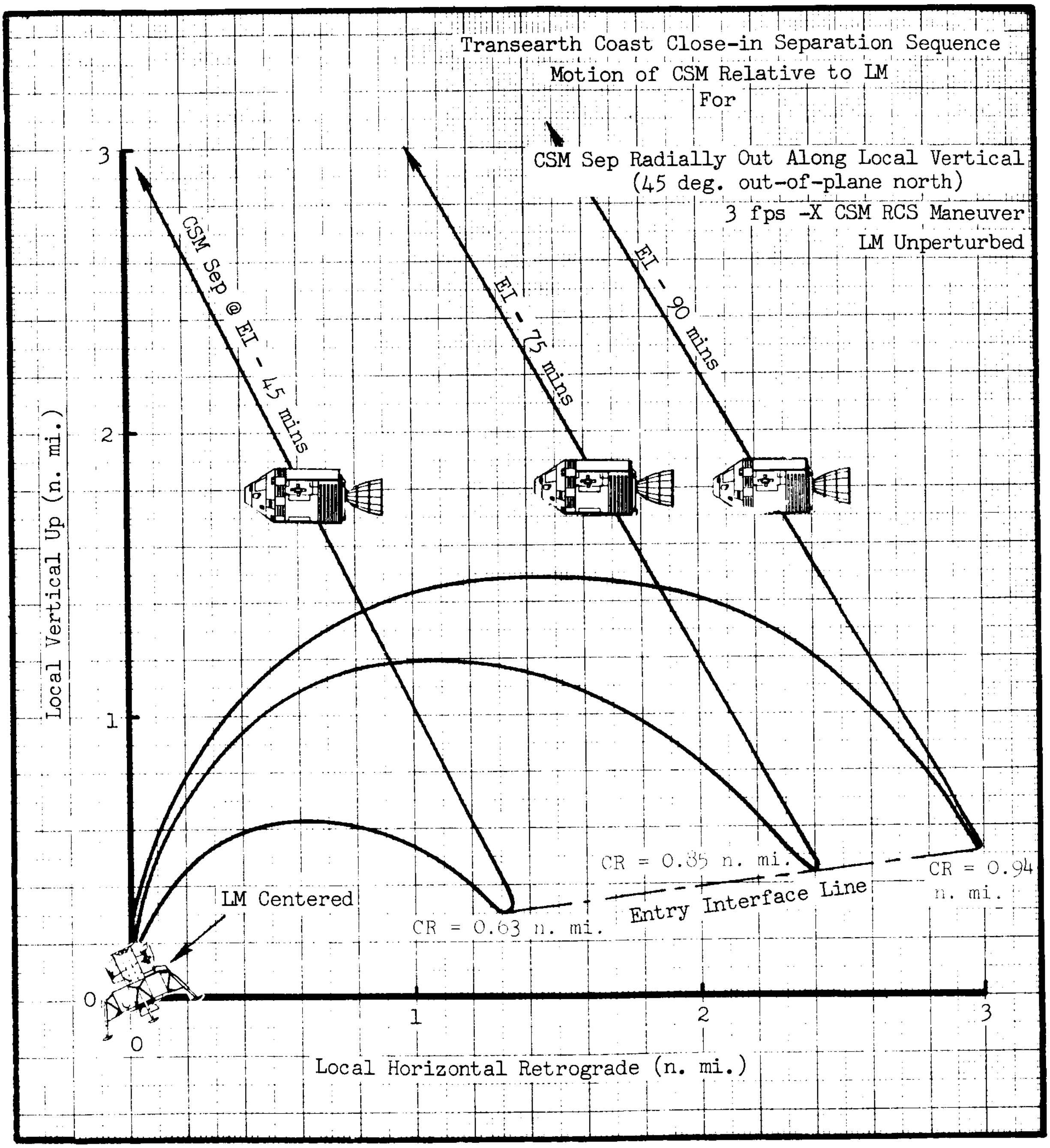


Figure 60.- Relative motion of LM for late LM jettison during TEC.

9.0 ENTRY PHASE

9.1 Nominal separation procedures

9.1.1 CM/SM separation for entry from TEC (figs. 61 and 62)

Time,[a] hr:min:sec, g.e.t.	Event
244:04:47.5	At t_{ff} = 17 minutes, the CSM performs the IMU alinement attitude check. The IMU alinement check is performed with CSM heads down, +X-axis alined 31.7° above the LOS to the backward horizon in the orbital plane (0° yaw). The CSM then yaws 45° north and holds this attitude for SM separation.
244:06:47.5	At t_{ff} = 15 minutes, the CM jettisons the SM and then orients to the entry attitude. Total relative ΔV imparted immediately at SEP is approximately 1.5 fps.
244:21:47.5	Entry interface.
244:35:23	Landing.

[a]For a nominal November 14, 1969, launch (ref. 5).

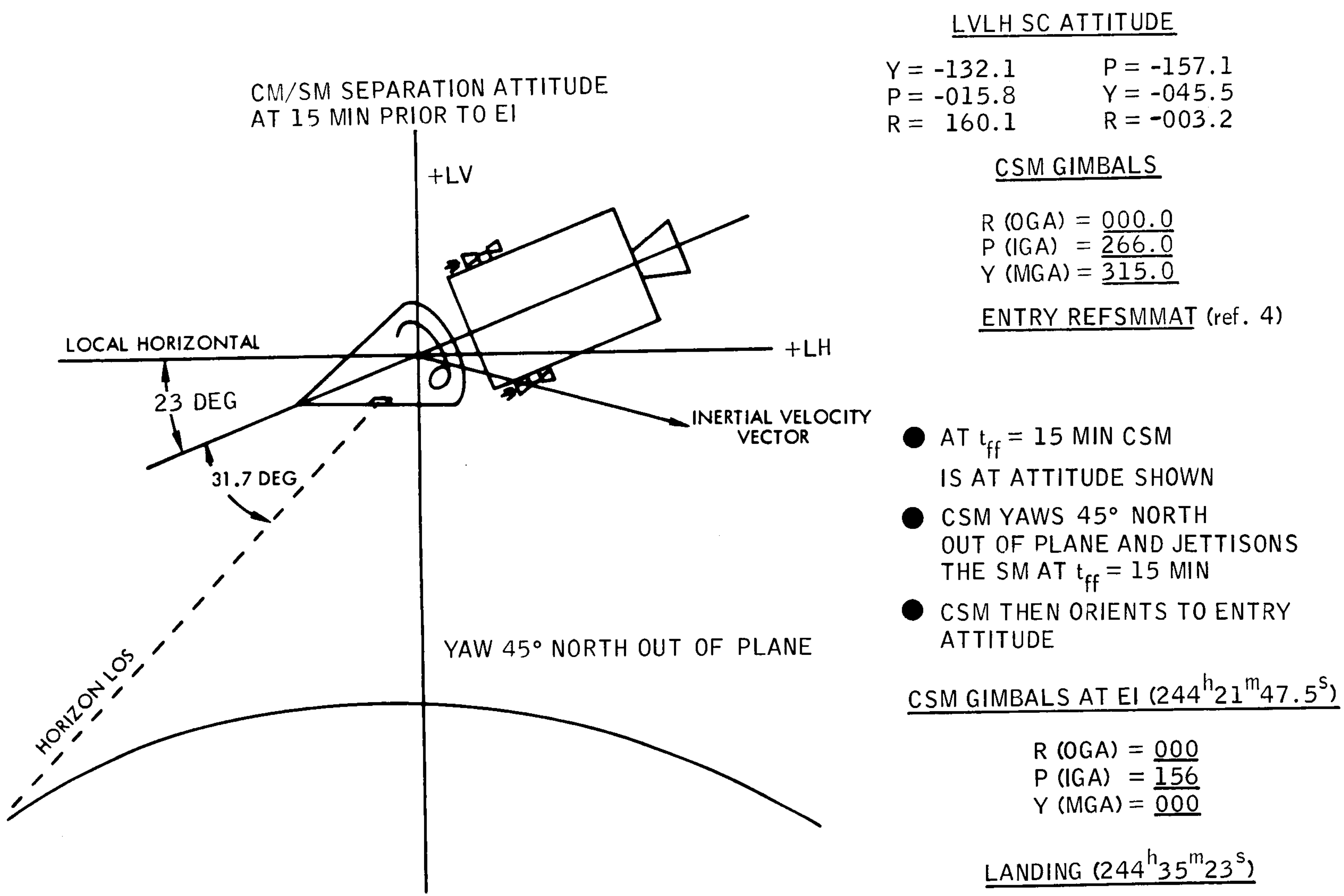


Figure 61.- Case: CM/SM separation; condition: SM jettison for nominal entry.

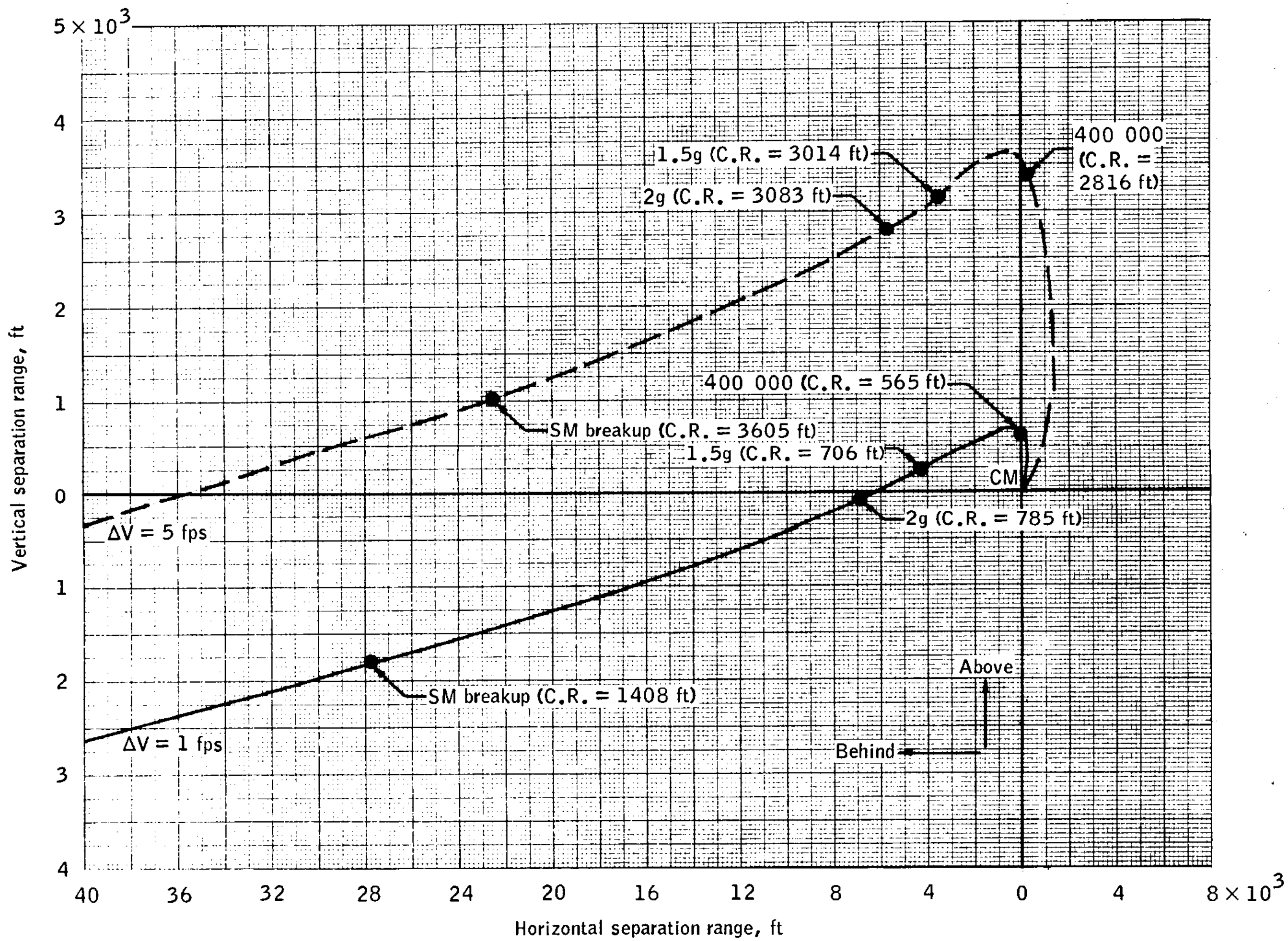


Figure 62.- SM motion relative to the CM for nominal entry from TEC (SM separation ΔV's of 1 and 5 fps).

9.1.2 CM/SM separation for entry from earth orbit (figs. 63 and 64)

a. The CSM remains in the deorbit burn attitude: CSM heads up, +X-axis 31.7° below the LOS to the rearward horizon.

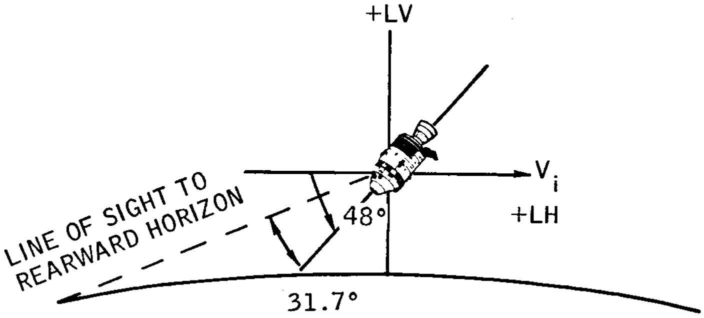
b. Yaw the CSM +X-axis 45° north out of plane from the deorbit burn attitude.

c. Jettison the SM and the DRPA.

d. Orient to the CM entry attitude.

e. Total relative ΔV imparted immediately at separation is approximately 1.3 fps between the CM and SM and approximately 7 ± 1 fps between the CM and the DRPA.

CM/SM SEPARATION
AND DRPA JETTISON ATTITUDE

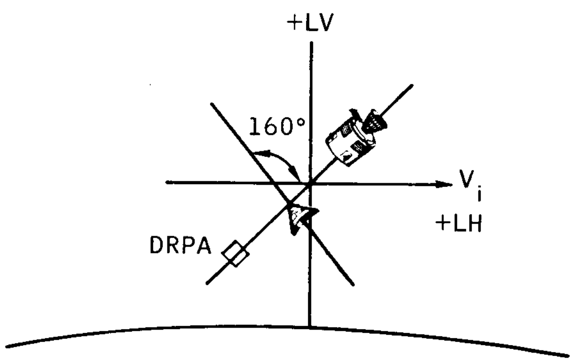


LVLH CSM ATTITUDE

R = 180
P = 31.7 BELOW LOS TO
REARWARD HORIZON
Y = -045
ROLL MUST BE PERFORMED PRIOR
TO HORIZON ALINEMENT AND
YAW AFTERWARDS

- CSM YAWS 45° NORTH FROM DEORBIT BURN ATTITUDE
- CM JETTISON SM AND DRPA

ENTRY ATTITUDE



LVLH CSM ATTITUDE
FOR ENTRY

Y = 000
P = 160
R = 000

- SM TRANSLATES AHEAD, ABOVE, AND SOUTH OF THE CM
- DRPA MOVES BELOW, BEHIND, AND NORTH OF THE CM
- CSM ORIENTS TO ENTRY ATTITUDE HEADS DOWN, FULL LIFT

Figure 63.- Case: CM/SM separation; condition: CM entry from earth orbit, and jettison of the SM and DRPA.

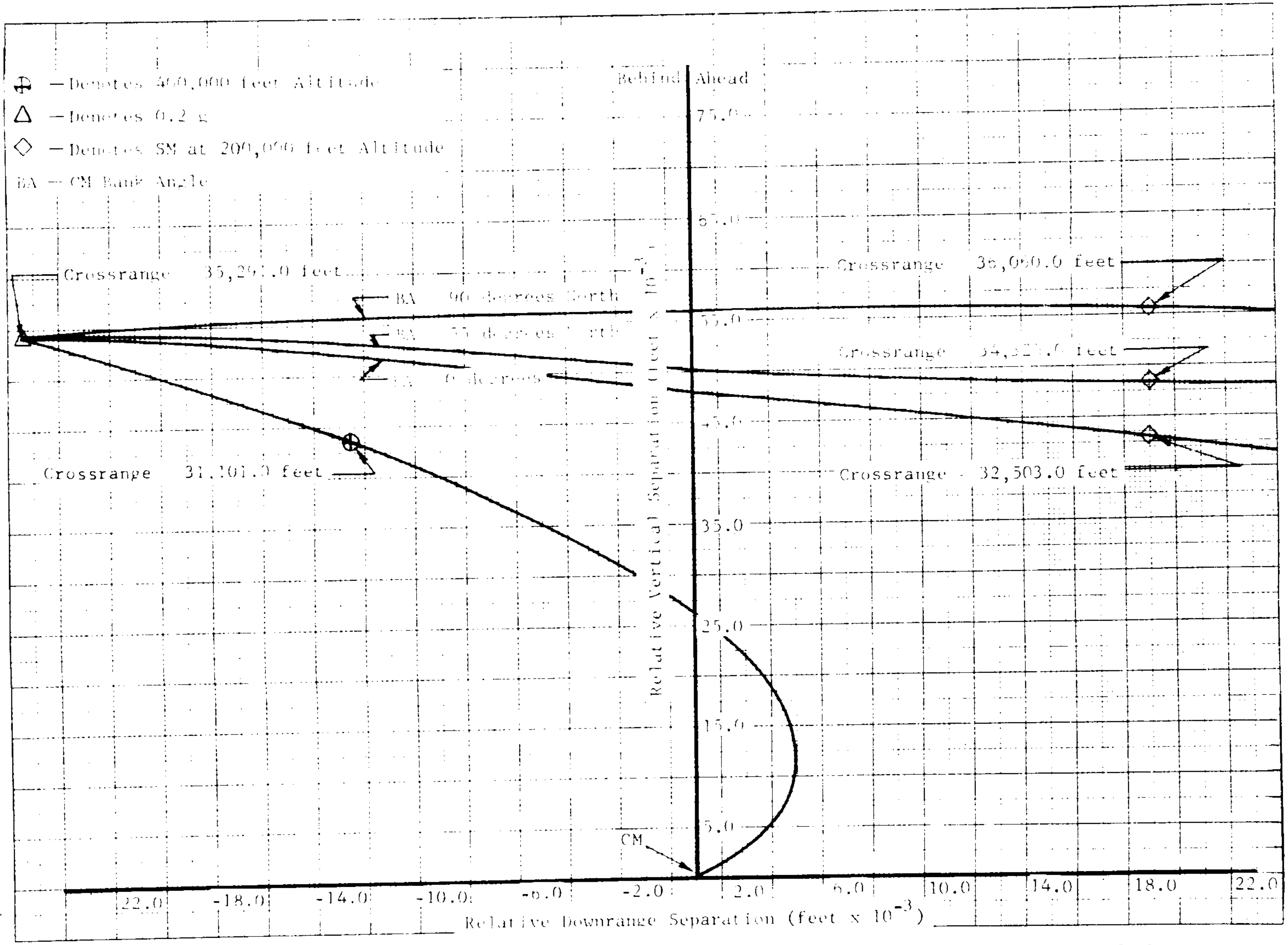


Figure 64.- SM motion to the CM for a typical earth orbit entry (SM separation $\Delta V = 65.8$ fps).

9.2 Nonnominal CM/SM separation procedures during entry (figs. 65 and 66)

9.2.1 Failed CM RCS thrusters

a. Perform MCC for shallow entry when possible.

b. Maneuver CSM to entry trim attitude with SM RCS.

c. Initiate CSM spinup with SM RCS for 20 deg/sec rolling ballistic entry.

d. Jettison SM at approximately 5 minutes prior to 400 000 feet with CM in entry attitude and a roll rate of 20 deg/sec.

e. Approximate ΔV imparted to SM is 0.54 fps and to CM is 0.94 fps.

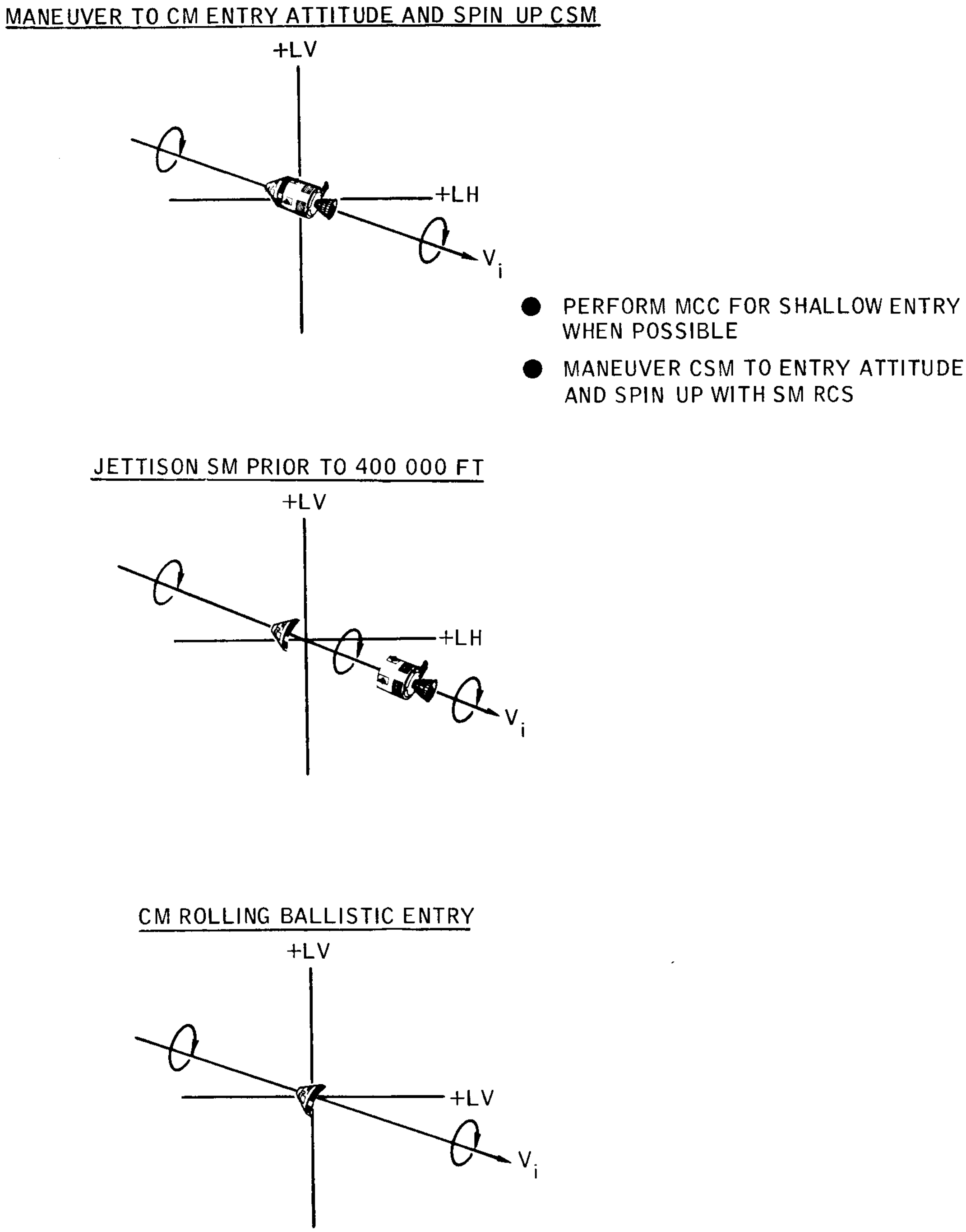


Figure 65.- Case: CM/SM separation; condition: failed CM RCS thrusters - TEC.

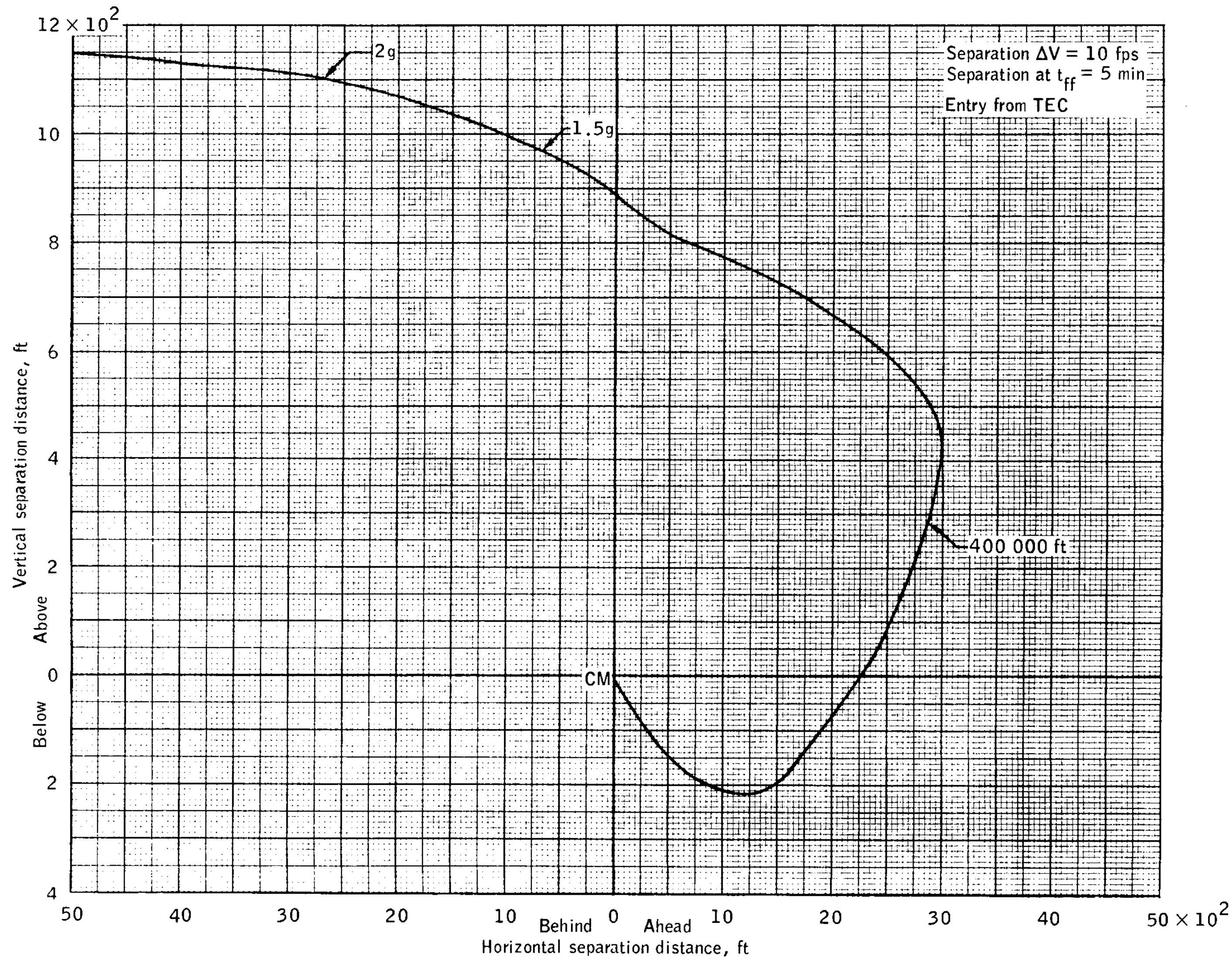


Figure 66.- SM relative motion for CM/SM separation occurring in entry attitude because of failed CM RCS thrusters.

TABLE I.- LAUNCH PAD REFSMMAT

(a) Applicable maneuvers

1. Launch

(b) Definition of REFSMMAT

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

SPACECRAFT
PLATFORM
STABLE
MEMBERS

ECI (MNBY)

(c) REFSMMAT components

XIX	=	0.707[illegible]70	XIY	=	-0.65236[illegible]70	XIZ	=	0.2[illegible]
YIX	=	-0.16414[illegible]	YIY	=	-0.525[illegible]	YIZ	=	-0.8[illegible]
ZIX	=	0.687[illegible]84	ZIY	=	0.5463[illegible]	ZIZ	=	-0.4788[illegible]

TABLE II.- LANDING SITE REFSMMAT

(a) Applicable maneuvers

1. LOI-1
2. LOI-2
3. MCC-4
4. CSM separation
5. LM DOI
6. LM powered descent

(b) Definition of REFSMMAT

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\substack{\text{SPACECRAFT}\\\text{PLATFORM}\\\text{STABLE}\\\text{MEMBERS}}} = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\substack{\text{ECI(MNBY) or}\\\text{MCI(MNBY)}}}$$

(c) REFSMMAT components

XIX =	-0.88000242	XIY =	0.45578804	XIZ =	0.13361524
YIX =	-0.16095158	YIY =	-0.55083074	YIZ =	0.81895062
ZIX =	0.44686726	ZIY =	0.69917292	ZIZ =	0.55809218

TABLE III.- LM ASCENT REFSMMAT

(a) Applicable maneuvers

1. LM ascent
2. CSI
3. CDH
4. TPI
5. CSM separation following LM jettison
6. LM deorbit

(b) Definition of REFSMMAT

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{SPACECRAFT PLATFORM STABLE MEMBERS}} = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI (MNBY) or MCI (MNBY)}}$$

(c) REFSMMAT components

XIX	=	-0.98074201	XIY	=	0.19321298	XIZ	=	0.02852860
YIX	=	-0.089507657	YIY	=	-0.57447133	YIZ	=	0.81361606
ZIX	=	0.17359009	ZIY	=	0.79539389	ZIZ	=	0.58070219

TABLE IV.- ENTRY REFSMMAT

(a) Applicable maneuvers

1. Entry

(b) Definition of REFSMMAT

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\substack{\text{SPACECRAFT} \\ \text{PLATFORM} \\ \text{STABLE} \\ \text{MEMBERS}}} = \begin{bmatrix} XIX & XIY & XIZ \\ YIX & YIY & YIZ \\ ZIX & ZIY & ZIZ \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{\text{ECI(MNBY)}}$$

(c) REFSMMAT components

XIX	=	.17049641	XIY	=	-[illegible]7769310	XIZ	=	-.12266696
YIX	=	.21985061	YIY	=	.15909631	YIZ	=	-.96247289
ZIX	=	.96051897	ZIY	=	.13712977	ZIZ	=	.24207177

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